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THE ROLE OF THE PROPORTIONALITY SCHEMA IN INTRODUCTORY HIGH SCHOOL CHEMISTRY

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF SECONDARY EDUCATION

EDMONTON, ALBERTA

FALL, 1976

ABSTRACT

The purpose of this study was to ascertain the extent to which students' perceptions of the proportionality schema are related to achievement in introductory chemistry. A total of 309 Grade 10 students comprised of an ALCHEM Materials sample (N=168) and a CHEM Study sample (N=14), enrolled in four Edmonton senior high schools, was tested under normal classroom conditions during the 1976 spring semester.

A set of four collectively administered Piagetian[1] Tasks (PT) served as a measure of students' cognitive functioning level. Two equivalent forms of a General Proportionality Test, GPT(A) and GPT(B), served to indicate students' performance on general proportional reasoning. Four subtests of a Chemistry Proportionality Test (CPT) dealt with the topics: Nomenclature and the Writing of Formulae, CPT(1); Chemical Reactions, CPT(2); the Mole Concept, CPT(3), and Gravimetric Stoichiometry, CPT(4). A Chemistry Achievement Test (CAT), covering all sections of the Chemistry 10 program, provided a general measure of achievement in chemistry.

In terms of cognitive functioning, the total sample (N=309) was classified as: concrete operational, 89 students (28.8%); transitional, 69 students (22.3%); early formal, 84 students (27.2%), and late formal, 67 students (21.7%). The existence of a prevalent

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[1] For purposes of the study the term 'Piagetian' is attached to these tasks. However, in view of the nature and format of the tasks in relation to classical clinical Piagetian tasks, the investigator notes a more appropriate term might be neo-Piagetian Tasks.

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'additive' mode of reasoning associated with concrete operational thinkers was noted with respect to selected proportionality tasks.

Significant correlations were found to exist between proportional reasoning in chemistry (CPT) and (i) achievement in chemistry (CAT), (ii) cognitive level (PT) and (iii) proportional reasoning in a non-chemistry context (GPT). Instruction in proportional reasoning in chemistry did not appear to enhance general proportional reasoning. Regression analysis to predict chemistry achievement (CAT) found only the chemistry proportionality subtests significant predictor variables. A principal factor solution identified three main factors, the first associated with the CPT subtests and achievement (CAT), and the second with the Piagetian Tasks (PT). The third factor contained high loadings for the verbal reasoning and analogy items on the two forms of the GPT. A significant chi-square in favor of the boys was noted between sex and cognitive level.

Related findings failed to detect a hierarchical structure associated with general proportional reasoning. However, results relating to proportional reasoning in a chemistry context supported an hypothesized sequence of capabilities (conversion → ratio → direct proportionality). Three areas of problem solving in introductory chemistry (mole relationships, interpretations of chemical equations and the use and effectiveness of dimensional-analysis) were discussed in relation to preliminary findings of the study.

ACKNOWLEDGEMENTS

To Dr. Heidi Kass, my supervisor, I am again indebted for the time and effort she has so freely given. Her example will serve as a worthy standard for the future.

Appreciation is also extended to my committee members, Drs. J.E. Bertie, T.E. Kieren, M.A. Nay, D. Nelson and L.L. Stewin, for their encouragement and support throughout the study.

I am also indebted to the teachers and students at Austin O'Brien Separate High School, Bonnie Doon Composite High School, Harry Ainlay Composite High School, M.E. Lazerte Composite High School, Parkview Junior High School and Queen Elizabeth Composite High School for their participation in the pilot and final studies. Special thanks to Frank Jenkins, Oliver Lantz, Dean Hunt and Howard Marcellus for their interest and assistance in testing, and to Ralph Schienbein for his invaluable help in test scoring and analysis.

To Mrs. Kay Baert for her care and excellence in typing the final draft.

And finally to my wonderful family, to Harry for coming along when he did, to Benji for his enthusiasm and humor, to Susan for her understanding and patience and to Maüschen for her love and support throughout.

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Chapter I

THE PROBLEM

Introduction to the Problem

Curriculum reform in science programs at the secondary level led in the 1960's to an increased emphasis on the structure of the subject matter. Somewhat lesser concern has been expressed for the organization of science curricula on the basis of knowledge about the students' cognitive development. If curriculum planning is to respect the sequence of cognitive development of students in general, and of individual students in particular, more information is required about the nature of cognitive development as it relates to specific aspects of the science curriculum. Research on cognitive development in science education has the potential to provide much needed detailed information about the students' thought processes or cognitive strategies in relation to the development of basic scientific concepts. Rather than merely using science content as a convenient subject-matter vehicle to test various psychological notions, the emphasis of research in science instruction should be directed towards more basic science-specific studies, with clearer implications for classroom practice.

Shulman and Tamir (1973) claim an increasingly strong need for this type of basic research:

> Such science relevant basic research would be on a topic like the cognitive development of science relevant concepts in young children, e.g. cause and effect, space, time, momentum. This sort of research is clearly in the tradition of Piaget. The purpose would be to identify some general normal expectations for the evolution of particular concepts around which curriculum developers and program writers could plan their creative endeavors (p. 1139).

While Piaget and his co-workers have identified a sequence of mental actions leading to students' understanding of principles and relationships in several phenomena commonly taught in high school science courses, Piaget's main developmental sequence lacks the 'fine structure' required to be truly helpful in detailed curriculum development. Fine structure studies attempt to identify characteristics of the student's thought processes within a stage or substage of cognitive functioning specific to a given concept or principle and could prove useful in supplementing Piaget's more general descriptions of child thought on scientific concepts.

The Piagetian stages of intellectual development provide a broad diagnostic tool for the design evaluation of school curricula in terms of the cognitive functioning level of the students. More specifically, within a given developmental stage the schemata described by Piaget provide a means to identify the types of understandings and thought processes available to individual students. These schemata, or mental structures, represent in Piaget's view the products of progressive internalization and symbolization of actions. These internal structures are thought to be hierarchically organized with the earliest schemata being physical actions upon the child's immediate environment. Through a series of more and more complex stages, the child is gradually able to free his thought processes from the motor activities upon which they are based. Each stage of schemata contains the preceding stage within its organization, but the earlier schemata are broadened, become more complex and are enriched by interaction with other schemata. The new level is a sensitively balanced 'equilibrium' of interlocking mental structures involving such transformations as identity (I),

negation (N), reciprocity (R), and correlation (C), the so-called INRC Group.

At the highest level, that of formal operational thought, the subject becomes capable of grouping the above transformations into a single system (the INRC Group). While Piaget's analysis of adolescent reasoning makes use of two particular realizations of the four group, the logical INRC group and the physical INRC group (Flavell, 1963, p. 215-216) the present discussion is limited to the physical INRC group described in greater detail in a later section.

Piaget maintains that all operational schemata at the formal level owe their existence to the evolution of the general lattice-group structure, the 'structure d'ensemble'. The eight formal schemata described by Piaget to analyze formal thought (Inhelder and Piaget, 1958, p. 318-329) represent certain substructures within the general structure d'ensemble, each one related to the group-lattice totality. The two abstract models of adolescent reasoning used by Piaget, the INRC group and the 16 combinatorial system, are said to derive from this general lattice structure.

The schema of proportions is one example of such a schema and its derivation is said to be directly related to the INRC group structure. That is, in its fullest sense the proportionality schema manifests itself in terms of the integrated INRC group structure.

Experiments conducted by Inhelder and Piaget (1958, Ch. 11-13) to investigate the role of the proportionality schema in adolescent thinkers dealt with selected physical phenomena — the balance problem, the inclined plane, the projection of shadows and centrifugal force. While the proportionality schema has received some attention in the field of

mathematics (i.e. ratio, proportions, fractions) its role in understanding of selected chemical concepts remains virtually unexplored. The present study is designed to investigate the role of proportional reasoning in introductory chemistry at the high school level. More specifically, the areas of chemistry which will be examined include nomenclature and the writing of formulae, chemical reactions, the 'mole' concept and gravimetric stoichiometry.

Formal Thought and the Proportionality Schema

This section discusses the proportionality schema in relation to formal thought and the transformations of the INRC physical group model and serves as background for the later section dealing with the application of proportional reasoning to chemical concepts.

The term 'schema' as used by Piaget indicates the general structure of actions or operations. A 'schema' is the generalisable aspect of coordinating actions that is applied to analogous situations. Hence we can speak of a schema of ordering, a schema of classification, a schema of probability and a schema of proportionality. As one of the eight formal operational schemata described by Piaget (Inhelder and Piaget, 1958, p. 307-329), the proportionality schema is the internalized structure or mental representation which enables the student to act on the mathematical equality of two ratios, e.g. $a/b = c/d$. The proportionality schema is operational in the sense that it directs the subject towards a specific action or transformation upon a given domain of objects. The proportionality schema provides the mechanism for the individual to equate two or more ratios in order to determine their equivalency. The ratio may arise from the manipulation of concrete

objects, as in the case of the paper clip tasks used by Karplus (1972, 1974) or it may arise from symbolic manipulation as is the case when algebraic notation is used in numerous proportionality expressions. However, whether the origins are concrete or abstract, the transformations of the INRC group model discussed below, particularly the transformations of inversion and reciprocity, are necessary for the schema to become fully operational.

In discussing formal thought it is convenient to view the adolescent's cognitive abilities in relation to a continuum ranging from the more general (the structure d'ensemble or integrated group-lattice structure underlying all formal thought) to the more specific or task-linked concepts used by adolescents in solving particular problems. Formal operational schemata, as a set of concepts or special operations, represent an intermediate level of generality (Inhelder and Piaget, 1958, p. 308, 309). Hence while each operational schema may have application to a specific problem under consideration, the schemata themselves have more general utility and reappear in varied situations and with reference to diverse problems. This susceptibility to varied applications is well illustrated by the proportionality schema in which the inversion and reciprocity transformations of the INRC group structure play so prominent a role.

The range of applicability of the proportionality schema has been examined by Inhelder and Piaget in four different experiments: 1) a simple balance experiment, where distances and weights compensate each other; 2) an inclined plane experiment, where inclinations and weights are involved; 3) the projection of shadows where diameters and distances compensate each other, and 4) a centrifugal force experiment where

weight and distance from the center of a disc compensate each other. Although derived from both lattice and INRC group structures (especially the latter) the proportionality schema manifests itself in all these problems in the form p, p*, q, q*, where p and q are the defined operations on a system and p* and q* are the corresponding negated or reversed operations.

Physical systems whose transformations exhibit this INRC group structure are of the type described below. The system first of all contains two distinct and different operations p and q, respectively. For instance in the balance problem, one may depress one arm of the balance either by adding weight to one arm (p) or by increasing the distance of the weight from the fulcrum (q). The corresponding opposing actions are decreasing the weight (p*) and decreasing the distance from the fulcrum (q*) in one arm. One expression of the proportionality schema is therefore:

$$\frac{p}{p^*} = \frac{q}{q^*} .$$

That is, an increase in weight is to a decrease in weight as the increase in distance is to the decrease in distance. In a series of experiments Inhelder and Piaget have presented children of concrete and formal operational ages with a number of problems involving physical systems of the p,p*,q,q* type (Inhelder and Piaget, 1958, Ch. 9, 10, 11, 13). The INRC group, in its physical system realization, is really a statement of the way in which p,p*,q,q* interrelate as a system (Flavell, 1963).

The interrelationships among p, q, p* and q* are of particular interest to Piaget in physical systems involving the above transformations.

Central to his analysis of adolescent thought is the manner in which the two complementary forms of reversibility — inversion and reciprocity, come into play.

The negation (or inversion) operation involves the literal canceling or undoing of an operation (p negates p* etc.). For example, in the balance problem addition of weight to one arm is negated by removal of weight from that arm. Reciprocity, however, represents another quite different form of reversible operation. Although any reciprocal operation has the same ultimate effect as the negation operation it is achieved by a different route. There is reciprocity when transformations performed in opposite directions do not annul each other but rather compensate or neutralize each other by posing a symmetrical equal-and-opposite counterforce. For example, the addition of weight to one side of the balance is the reciprocal transformation of adding weight to the other side because it neutralizes its effect (e.g. q* is the reciprocal of p). The quality of action and reaction is the general form of this compensation by reciprocity. At the level of formal operations these two forms of reversibility are said to be integrated into a single system, the INRC group. That is, the INRC transformations as an integrating group structure may be used to describe the properties of the proportionality schema. If a weight destroys the balance, the weight can be taken off (negation), or an equal weight can be added at an equal distance on the other arm (reciprocity), or a heavier weight can be added closer to the fulcrum or a lighter weight further away (correlativity), or all the weights can be removed to restore the balance to equilibrium (identity).

Piaget maintains that before a system of proportions comes into play, that is, before a subject arrives at the calculation of numerical relations, he isolates an anticipatory schema for qualitative proportionality (Inhelder and Piaget, 1958, p 316). This qualitative schema of logical proportions corresponds to the global intuition of proportionality with which the subject begins in the earlier phases of the development of the schema. In the balance problem this initial qualitative schema is based on the reciprocity of weights and distances. Once the two forms of reversibility are acquired, the subject can insert the numerical values which are furnished by his measurements, thus leading to the discovery of metrical proportions.

The four transformations I, N, R, and C of the four group described by Piaget (1950, 1958) correspond to the elements of a true mathematical group under the operation of multiplication or combination (Grossman and Magnus, 1964). That is, under the binary operation of multiplication, the set of four transformations constitute a true mathematical group (G) such that the following axioms are satisfied:

1. Associativity: For any elements I, N, R, or C of G,

   $N(RC) = (NR)C$

2. Identity: There is a unique element I in G such that, for every element of G,

   $IN = NI = N, \quad IR = RI = R$, etc.

3. Inversion: For any element of G, there exists a unique element such that,

   $N(N^{-1}) = (N^{-1})N = I, \quad R(R^{-1}) = (R^{-1})R = I.$

At the formal level, stage III, subjects become able to understand transformations by inversion (N) and reciprocity (R) and to group them into a single system (I,N,R, and NR = C). This possibility of reasoning in terms of a group structure (INRC) indicates at least an intuitive understanding of the equalities NR = IC, RC = IN, NC = IR, etc., the equalities between the products of two transformations.

According to Piaget the notion of metric proportionality does not appear until the formal substage IIIA, and only rarely appears before substage IIIB (Inhelder and Piaget, 1958, p 173). This finding also appears to be the case in tasks other than the balance scale experiments (Inhelder and Piaget, 1958, p 177).

An earlier study (Wheeler, 1973) into the nature of misconceptions held by secondary high school students in the area of chemical equilibrium attempted to associate specific transformations of the INRC group model with selected problems in chemical equilibrium. However, since the INRC transformations form a group in the mathematical sense, with each operation bearing definite relationships to the others, difficulties are encountered when one attempts to associate a given problem or test item with a single transformation. Although the integration of the two notions of reversibility were found to be fundamental to the understanding of chemical equilibrium, several items used in the previous study could not be associated with any single transformation of the INRC model. Rather than attempt to apply specific INRC transformations to selected concepts in chemistry involving proportional reasoning, the interpretation placed on the INRC model in the present study is in relation to the understanding of certain chemical equalities which may involve the INRC

group transformations. While the ability to reason in terms of a group structure is seen to involve the understanding of the chemical equivalencies outlined in the following section, the nature and limited scope of topics covered at the introductory high school chemistry level prohibit a more definitive investigation of other possible transformation equalities analogous to those inherent in the INRC model.

Proportional Reasoning in Chemistry

In attempting to relate the schema of proportionality to selected concepts in introductory high school chemistry, four major areas of investigation have been identified.

1. *Chemical nomenclature and the writing of formulae.* These topics are normally introduced early as basic tools for further application in more advanced areas in chemistry. Forms of proportionality exhibited at this level are related to the basic laws of chemical change (Law of Definite Proportions, Law of Multiple Proportions) and to fundamental aspects of the nature of matter (e.g. atomic masses). To illustrate, atomic masses are based on the isotopic composition of elements and may be said to represent a proportional average.

Consider also the numerous instances in which students apply basic rules to obtain chemical formulae for specific compounds. Given the chemical symbols and valences for the ions concerned, the student determines the simplest whole number ratio of ions such that the net sum of ionic charges is zero. The numbers representing the simplest whole number ratio of ions are written as subscripts in the chemical formula. For example, calcium chloride is written $CaCl_2$ since 1:2 is the simplest whole number ratio required to achieve a net electrical charge of zero. Formulae for other ionic binary compounds (e.g. Al_2O_3, K_2S) and those involving complex ions (e.g. $Ca(ClO_3)_2$, $Ba(BrO_3)_2$), are

determined in like manner.

It is important that the student recognize the invariance of the combining ratio as given by the simplest or empirical formula. This is especially important when dealing with ionic solids where the number of ions of the given elements in the aggregate may vary without affecting the fixed ratio of ions. It seems unlikely that the study of chemistry and chemical transformations can begin until the student acquires the notion of invariance of chemical substances (i.e. composition) in spite of certain physical or other superficial changes that may be observed. The chemical invariance of certain substances under the action of heat, for example, appears fundamental to the understanding of physical changes and their relationship to chemical changes.

2. *Gravimetric stoichiometry*. The study of quantitative relationships implied by a chemical reaction (stoichiometry) contains a number of instances in which proportional reasoning is of central importance. In particular, the concept of the 'mole' has wide applicability in this area and serves to illustrate a number of types of proportionality problems.

The concept of a gram-molecular weight of a substance (mole) or molar mass is usually presented at an early stage in introductory chemistry at the high school level. Often the mole concept proves to be a troublesome one for students. Part of the difficulty may arise from the fact that while a mole constitutes a certain mass for a given substance, the real significance of the mole is more useful when connected with a number of particles (Avogadro's number of atoms, ions, molecules, etc.) rather than their mass. That is, while the actual

mass of a mole varies for different substances, the number of particles remains invariant. Furthermore, in the case of gaseous substances the mole is often dealt with in terms of a given volume under standard temperature and pressure conditions. Clearly conservation concepts (i.e. conservation of mass for particular substances, conservation of number and volume for all substances) are prerequisite schemata for the 'mole' application in chemistry. Consider the example where different substances are presented to a student and he is asked to determine what weight of substance A contains the same number of molecules as a given weight of substance B. Given the molar masses of the respective substances, and realizing the invariance of the number of molecules represented by a mole, the student will be able to set up a simple proportion to obtain the answer involving the proportionality schema.

Stoichiometric problems dealing with the mole concept may be conveniently categorized into three main types:

i) *Conversion problems*

Here students given an initial mass convert directly to moles of a substance (A) using the relationship,

$$\text{moles of A} = \frac{\text{mass of A}}{\text{molar mass of A}} = \frac{\text{grams}}{\text{grams per mol.}}$$

Conversely a number of instances require the conversion of a given mass of substance (A) back into moles as given by:

$$\text{mass of A} = (\text{moles of A}) \times (\text{molar mass of A}).$$

In relation to transformations of the INRC group discussed earlier, the notion of reversibility seems particularly relevant for students' ability to apply proportional reasoning when dealing with conversion

problems of this nature. For example the operation of decreasing the mass of a given substance has a negating (or inversion) effect on the number of moles present. However a similar decrease in the number of moles could result via a reciprocal operation for the same mass of substance, if the substance dealt with possessed a greater molar mass. The realization of these two forms of reversibility (negation and reciprocity) leads to a firmer understanding of the 'mole' concept and its application to a number of areas in chemistry. Less frequent but equally important conversions may require the expression of moles in terms of volumes under certain conditions (e.g. when dealing with gaseous substances) or in terms of the number of particles (ions, atoms, molecules, etc.).

ii) *Ratio problems*

Application of the mole concept in gravimetric stoichiometry is often discussed in relation to the reacting mole ratios implicit in a balanced chemical reaction. Consider the chemical equation represented by:

$$aA + bB = cC + dD,$$

where a, b, c, and d represent the numerical coefficients of the balanced chemical reaction. Here the mole is treated in terms of a reacting ratio dependent upon the substances involved. That is, in this case 'a' moles of substance A reacts with 'b' moles of B to form 'c' and 'd' moles, respectively, of the products C and D.

Given, for example, x moles of A, the number of moles of reactant B required for reaction is determined by taking into consideration the mole ratio in which the two reactants combine, namely

$$\frac{\text{moles of B}}{\text{moles of A}} = \frac{b}{a} .$$

Hence the required number of moles of B required for reaction with x moles of A is given by, (x moles of A) x (mole ratio, $\frac{b}{a}$).

In addition to the more obvious numerical relationships required to solve quantitative problems of this nature, the student must be able to freely move from a microscopic or molecular perspective of the reaction (as implied by the balanced equation) to the more frequent macroscopic or molar interpretation normally associated with laboratory work. That is, the impracticality in most cases of discussing individual atoms or molecules in a reaction entails an implicit understanding of the 1:1 proportionality existing between the molecular and molar connotations of a chemical reaction. Unless the student understands that the number of particles represented by a mole of any substance (Avogadro's number or 6.02×10^{23}) remains invariant, this relationship will undoubtedly be a major source of difficulty. Certain items of the Chemical Proportionality Test (CPT) used in the present study are designed to measure students' understanding of the relationship between the micro and macro interpretations associated with chemical formulae and equations.

iii) *Proportionality problems*

Proportionality implies the understanding of the equality of two ratios, $\frac{x}{y} = \frac{x^1}{y^1}$. According to Piaget the discovery of the equivalence of two ratios is intimately related to notions of inversion and reciprocity found in the INRC group model and does not occur before the formal level (Inhelder and Piaget, 1958, p 314). In introductory chemistry, a number of examples of the proportionality schema are present in the form p,p*,

q,q* described by Inhelder and Piaget. This schema of metrical proportions implies an equivalence between ratios such that:

$$\text{if } \frac{p}{q} = \frac{p^*}{q^*}, \text{ then } \frac{p}{p^*} = \frac{q}{q^*}.$$

Using the previous illustration from chemistry,

$$aA + bB = cC + dD,$$

a number of proportions consisting of equivalent mole ratios can be obtained, e.g.

$$\frac{a}{b} = \frac{a^1}{b^1}, \quad \frac{b}{c} = \frac{b^1}{c^1}, \quad \frac{a}{d} = \frac{a^1}{d^1}, \text{ etc.}$$

The realization of the equivalency between respective ratios as determined by a balanced chemical reaction appears prerequisite to a sound chemical understanding of stoichiometry. This would apply in instances where stoichiometric problems are presented both in terms of a fractional approach where chemical calculations are treated in terms of algebraic expressions derived from balanced chemical reactions or in terms of reacting mole ratios. The present study attempts to assess the relative effectiveness of *both* approaches to the treatment of proportionality in stoichiometric calculations. Items of the Chemistry Proportionality Test (CPT) used in the present study are designed to investigate students' perception of the proportionality schema in both areas. In addition to ascertaining whether or not these components of the proportionality schema are hierarchical in nature, the test items serve to measure students' ability to separate variables in a chemical context. The inclusion in the present study of the General Proportionality Test (GPT) which consists of items measuring aspects of the proportionality schema similar to those in the CPT will serve as a

control to determine whether findings with respect to proportional reasoning in chemistry are specific to the subject matter studied.

Statement of the Problem

The main purpose of this investigation is to ascertain the extent to which students' perceptions of the proportionality schema are related to achievement in introductory chemistry. The central question of the study is: *Is the ability to apply proportional reasoning a significant factor in achievement in selected areas in introductory high school chemistry?*

Need for the Study

In contrast to the considerable quantity of research associated with concrete operational thought and the studies dealing with the transition between pre-operational and operational thought, few experiments have dealt specifically with students' ability to perform tasks requiring formal reasoning. This situation has several plausible explanations. First, the nature of the formal operational tasks themselves are sufficiently different from tasks typically encountered in earlier stages. The phenomenon of adolescents learning to solve introductory chemistry problems in school, for example, may be somewhat less intriguing to the psychological researcher than 5-year-olds insisting that changing a clay ball into a sausage affects the clay.

According to Siegler et al. (1973) an additional factor associated with research on adolescent reasoning is the complexity of Inhelder and Piaget's description of formal reasoning in terms of logical structures, interpropositional operations, and binary operations which may tend to discourage many otherwise interested investigators. Further, although

investigators have attempted to refute or support the initial findings of Smedslund (e.g. 1961), Lovell (e.g. 1961) and Elkind (e.g. 1961), only recently has increased research attention been directed to the role of formal thought in selected areas of science (e.g. Karplus, 1976; Herron, 1975; Lawson, 1974; Ball and Sayre, 1974).

If research in science teaching is to be truly helpful for the classroom teacher it must be concerned with detailed curriculum specifications and prescriptions. Detailed curriculum specification requires that one is able to assess basic conceptual demands placed on the student in order to more fully comprehend a particular concept in science. An analysis based on the conceptual demands in introductory chemistry, for example, could prove useful to the classroom teacher for either a prescription or modification of a given instructional approach. The work of Ingle and Shayer (1971) and Shayer (1972) on the conceptual demands inherent in Nuffield O-level chemistry and physics holds considerable promise in this area. As a theory of mental development, Piaget's formulations have considerable diagnostic implications for science education, yet Piaget himself has cautioned against the hasty and ill-considered application of his work until much more specific research into the educational effect of his theory has been undertaken (Ripple and Rockcastle, 1964). The present study is an example of an in-depth classroom investigation into a specific content area in science at the introductory high school chemistry level.

Evidence is available to indicate that an appreciable number of students may not be functioning at the cognitive level of which, according to Piaget and others, they should be capable (Field and Cropley, 1968; Bass and Montague, 1972; Buell and Bradley, 1972; Ball and Sayre,

1974). However, before any action can be undertaken to facilitate a shift towards the formal level of thought in the science classroom, insight into the nature of students' problems on specific tasks and their conceptual demands must be gained. Piaget's basic concern is with the description of the 'generalized knower' (the epistemic subject) and while such description sheds profound insight on epistemological problems, it reveals little about the variations in the ability of the individual student to use certain operational schemata according to content, context, or subject-matter area. The present investigation into the role of the proportionality schema in chemistry may be indicative of possible approaches that could be utilized to study the development of selected schemata across a wide range of content areas. High school chemistry abounds with instances in which proportionality is of central importance to the chemical understanding of the principle or concept in question.

Procedure

The procedure followed in the investigation was as follows: Prior to the commencement of any instruction in chemistry, all Grade 10 chemistry students cooperating in the study were collectively administered the set of Piagetian Tasks (PT) during regular classroom periods. The entire sample was then randomly assigned and administered one form of the General Proportionality Test (GPT). Subtests of the Chemistry Proportionality Test (CPT) were administered during regular class periods following the conclusion of each appropriate unit throughout the semester period. At the conclusion of the semester, all students in the sample were administered the alternate equivalent form

of the General Proportionality Test (GPT) as a posttest measure. The Chemistry Achievement Test (CAT), administered at the conclusion of the semester, served as the main achievement criterion.

A more thorough account of the nature and construction of the tests used in the study, the pilot investigation of these instruments and the testing sequence are presented in Chapter III.

Definition of Terms

A number of definitions of key terms as used in the study together with a brief explanation of the test instruments are presented below.

INRC Group Model (Piaget): The group of four transformations — identity (I), negation (N), reciprocity (R), and correlativity (C) — corresponding to certain fundamental structures of thought at the formal level. For purposes of the study the INRC group model refers to the physical INRC group as defined by Flavell (1963, p. 217).

Operation: Any representational act which is an integral part of an organized network of related acts (Flavell, 1963, p. 166). Operations constitute among themselves closed systems whose most important characteristic is their reversibility. The isolated operation cannot be the proper unit of analysis because it gains its meaning from the system of which it is a part.

Reversibility: The possibility of performing a given action in a reversed direction. Its two chief forms are: negation ($N(p) = p^*$) and reciprocity ($R(p) = q^*$). Reversibility is the basic criterion of an underlying operational structure.

Transformation: The name given to the process by which operations can

be changed in form. For example, the inverse or negation of the operation of adding weight to a balance is the removal of that weight. The system contains two distinct and different operations, p and q, which have exactly equivalent outcomes, and two other operations, p* and q*, which nullify or undo p and q, respectively.

Chemistry Achievement Test (CAT): A 60 item, four option, multiple choice open-book examination of 80 minutes' duration. Items contained in the CAT were drawn from a pool of some 400 tested items available from the Testing Division of the Edmonton Public School Board for which item statistics are available. The CAT covers all major topics in the Chemistry 10 course, including the four areas to which the present study is directed and is used as a measure of general achievement in introductory chemistry.

General Proportionality Test (GPT, Form A and Form B): A test devised for the present investigation consisting of two logically equivalent forms (A and B). The first section of the GPT consists of 15 multiple choice items dealing with ratio and proportion as they might be found in common situations. The second section consists of several short answer type questions related to ratio and proportion including verbal reasoning questions, verbal analogy questions and numerical series questions.

Chemistry Proportionality Test (CPT): A combined multiple choice and short answer type test constructed for the study covering aspects of the proportionality schema as they relate to introductory chemistry concepts found in the high school curriculum. The four subtests of the CPT cover the following topics: chemical nomenclature and the writing of formulae, CPT(1); chemical reactions,

CPT(2); the 'mole' concept, CPT(3), and gravimetric stoichiometry, CPT(4). Items of the CPT subtests were constructed to illustrate analogous aspects of the proportionality schema in a chemistry context to those found in the General Proportionality Test (GPT). The CPT subtests are discussed in greater detail in Chapter III.

Piagetian Tasks:[1] These refer to the following paper-and-pencil tasks used in the present study:

i) *Balance Problem (BP)*: (Inhelder and Piaget, 1958; Lovell, 1961; Lunzer and Pumfrey, 1966).

ii) *Ratio Task (RT)*: a modification of the Form B paper clip ratio task used by Karplus et al. (1974) described in an earlier section.

iii) *Metric Puzzle (MP)*: a direct proportionality task requiring students to predict a distance in kilometers given basic data necessary for the conversion of miles to kilometers.

iv) *Islands Puzzle (IP)*: a paper-and-pencil formal operational task which requires students to formulate a number of possible plane routes among four islands, given certain constraints.

The set of Piagetian Tasks are presented together in booklet form in Appendix B.

Proportionality Schema: refers to the formal operational schema as described by Inhelder and Piaget (1958, p. 176-181, 314-317), and defined in relation to the INRC group transformations. The proportionality schema is said to become fully operational when the subject is capable of reasoning in terms of the INRC group structure and understands the equalities between the products of two transformations, e.g. NR = IC and RC = IN etc. In the case of mathematical proportions the proportionality schema leads to an understanding of the equality of two ratios, $x/y = x'/y'$.

Proportional Reasoning: refers in the present study to the subject's

ability to apply the proportionality schema to a variety of problems and situations involving transformations of the INRC group structure. A measure of the subject's perception of the proportionality schema will be obtained by performance on items of the Chemistry Proportionality Test (CPT) and the General Proportionality Test (GPT).

Delimitations of the Study

The relatively small sample of the study (N = 309) and narrow range of concepts covered, coupled with the single grade level (Grade 10) dealt with in the study, taken together, represent an important delimitation that should be noted. These practical considerations were deemed necessary in order to achieve the required focus in the investigation. In view of these considerations no attempt will be made to generalize to other possible student groups or grade levels not included in the investigation.

Further, as the Chemistry Achievement Test (CAT) is confined to topics commonly found in introductory high school chemistry, any generalizations regarding overall chemistry achievement will have to be restricted to the level and topics covered by the CAT at the Grade 10 level. While teacher methodology and degree of emphasis given to the topics covered by the CAT are not strictly controlled, participating teachers were chosen on their interest in the study and their involvement in the development of the chemistry program used in the investigation. The classroom teachers identified for cooperation in the study have been associated with the early design, development and implementation of the present Grade 10 chemistry ALCHEM Materials course and are

felt to more fully appreciate and adhere to the philosophy and instructional techniques embodied in the program than a random selection of Chem 10 teachers. That is, participation in the study was purely on a voluntary basis. This resulted in a select group of interested, highly experienced, full time classroom practitioners to serve as cooperating teachers in the investigation. In addition, all participating teachers were interviewed to ascertain whether their particular instruction of the content involved any obvious omissions or irregular situations which might affect the interpretation of results of the study.

The nature of the set of Piagetian Tasks used which were mainly of the non-verbal, paper-and-pencil variety, necessitates the delimitation of any generalizations regarding the students' performance on these tasks to those situations tested. While the investigator notes that certain cognitive skills may be more relevant to the proportionality schema than others, an overemphasis on the specificity of these competencies should not be encouraged. This relates to the difficulty mentioned earlier when one attempts to view a specific cognitive ability in isolation for study purposes when the ability in question is more properly viewed as a function of an interrelated structure, such as the INRC group. Further, the application of the INRC group model to proportionality problems in introductory chemistry only serves as an example of one area of application of formal operations in adolescent thinking. A more definitive study to fully investigate the role of each of the INRC transformations in the learning of chemical concepts is clearly beyond the scope of this study, although the approach taken may reveal some guidelines for such research.

Limitations of the Study

One area of limitation concerns the validity and reliability of the test instruments used in the study. The reliability and validity of the Chemistry Achievement Test (CAT) and the reliability of the Chemistry Proportionality Test (CPT), and the General Proportionality Test (GPT) can be assessed statistically. Items on the CPT and the GPT were designed to measure certain aspects of the proportionality schema as perceived by the investigator, in consultation with experienced people in the field. A validity assessment of these instruments was based on three pilot administrations of these tests and feedback from professors and teachers in science education concerning the difficulty, appropriateness and clarity of the test items.

At present there exists no statistical means of assessing the construct validity of the set of Piagetian Tasks used in the present study to provide a measure of the level of cognitive functioning of the students. However, the tasks closely parallel those used in classical studies (Inhelder and Piaget, 1958) and the Ratio Task has been used in several other studies (e.g. Karplus and Karplus, 1972). The acceptability and familiarity of the chosen tasks serve as two independent measures to strengthen the degree of validity associated with these instruments when used as proposed in the present investigation. Both the feasibility and appropriateness of these group administered tasks were discussed with Piagetian experts beforehand. A section in the review of related literature, entitled "Piagetian Studies in Science" addresses itself more directly to the techniques used in the assessment of cognitive functioning and to considerations

involving their reliability and validity.

Another limitation of the study has to do with the possible oversimplification of the nature of the proportionality schema in introductory high school chemistry as measured by the Chemistry Proportionality Test (CPT). Items of the CPT were designed to measure certain aspects of the schema as perceived by the investigator in consultation with experienced people in the field. The types of proportionality problems identified by the subtests of the instrument are those which are *deemed critical* on the basis of the judgment and experience of skilled people in the field for a firm understanding of chemical proportionality at the introductory high school level based on the present program and are not necessarily exhaustive of the domain of the schema to high school chemistry.

Research Hypotheses

As the study is seen to encompass three major types of variables, the hypotheses are stated accordingly:

1. *Proportional Reasoning and Achievement in Chemistry*

    1.1. *There is no significant relationship between student ability to apply proportional reasoning in chemistry (CPT) and achievement in chemistry (CAT).*

    1.2. *There is no significant relationship between student ability to apply general proportional reasoning (GPT) and achievement in chemistry (CAT).*

2. *Proportional Reasoning and Cognitive Level*

    2.1. *There is no significant relationship between student scores on tests involving proportional reasoning in chemistry (CPT) and cognitive functioning level as measured by Piagetian criteria indicative of proportional reasoning (PT).*

    2.2. *There is no significant relationship between student scores on tests involving general proportional reasoning (GPT) and cognitive functioning level as measured by the Piagetian tasks (PT).*

3. *Proportional Reasoning in Chemistry and Non-Chemistry Contexts*

   3.1. *There is no significant relationship between students' ability to apply proportional reasoning in chemistry (CPT) and application of proportionality in areas not content-specific (GPT).*

The investigation of the role of proportionality in the growth of basic introductory concepts in chemistry also involves the related questions:

1. *Do tasks measuring proportional reasoning represent a hierarchy of capabilities?* This will be studied in both the (i) chemical context and (ii) the non-chemical context.

(i) *Chemical context.* Student performance on the Chemistry Proportionality Test (CPT) used in the present study will be examined to determine whether those items measuring various aspects of the proportionality schema (i.e. direct conversion, ratio and equivalency of ratios) form a hierarchy of capabilities. That is, student performance on items of the CPT will be examined using a task analysis procedure to ascertain whether the type of proportionality problems are suggestive of a hierarchical structure. It may be, for example, that students capable of solving conversion-type problems and items introducing simple reacting ratios are unable to apply these concepts to problems in chemistry which deal with ratio equivalency.

(ii) *Non-chemical context.* A task analysis will be performed on the items of the General Proportionality Test (GPT) in an attempt to ascertain whether the subtests (conversion, ratio, proportion) reveal a hierarchical structure of capabilities with respect to the application of proportionality in common situations.

2. *Is there a significant relationship between sex and cognitive level for the sample?*

Summary

Utilizing a Piagetian conceptual framework, the proportionality schema has been discussed in relationship to formal thought and the transformations of the INRC group model. A discussion of the applicability of the schema to instances of proportional reasoning in introductory chemistry follows. Performance on different tasks indicative of proportional reasoning is hypothesized as having a relationship to academic achievement in chemistry. The investigation of this relationship constitutes the major purpose of the present study. The major aspects of the procedure for achieving this purpose have been outlined, followed by the presentation of the definitions, delimitations, limitations and research hypotheses of the investigation. Chapter I concludes with a brief overview of the report.

Overview

This introductory chapter is followed by a review of current literature on Piagetian studies in science, studies related to the teaching of secondary school chemistry and those studies dealing more directly with the proportionality schema. Chapter III discusses the preliminary investigations connected with the present study and presents the procedure and details of the various testing instruments used in the investigation. The design of the study is presented and discussed in Chapter III. A description of the analysis used and the results of the study are presented and discussed in Chapter IV. The report concludes with Chapter V which consists of the summary of the study, and the major conclusions and recommendations for further possible research.

Chapter II

REVIEW OF RELATED LITERATURE

Research studies which pertain directly to the present study appear to be relatively scarce. However, a number of studies considered relevant to the present context are reviewed under the headings: Piagetian Studies in Science, Studies Related to the Teaching of Secondary School Chemistry, and Studies Related to the Proportionality Schema.

Piagetian Studies in Science

Science educators have witnessed numerous advances in theory and practice during the past decade. One of the most important of these has been the study and application of Jean Piaget's work as it relates to students' intellectual development. The body of research which has developed from the application of Piagetian techniques has truly been immense. Major implications arising out of science education research using a Piagetian framework relate to (i) the sequencing of science instruction, (ii) science instruction and methodology, and (iii) science content appropriateness. While it is not the purpose of this section to review research studies in these three areas, an example in each will serve to illustrate typical approaches.

Firstly, Piaget's stages of intellectual development provide a framework for the sequencing of science activities. According to Elkind (1972) these stages parallel the stages that characterize the development of any science, namely: observation (sensorimotor period or the search for conservation); naming and labeling (preoperational

period or the search for representation); formal classification and quantification (concrete operational period or the search for relations) and controlled experimentation and theory building (formal operational period or the search for comprehension). The study of Bass and Montague (1972) is an example of an attempt to determine the sequencing of selected problems within a given level, that of formal operational thought. Their study dealt with two problems from the general area of physical science: equilibrium in the simple balance, and equilibrium of a cart on an inclined plane. Bass and Montague attempted to translate the developmental sequences as described by Inhelder and Piaget (1958) for these two problems into a hierarchy of instructional objectives and instructional materials. Objectives consistent with Piaget's findings on the balance and inclined plane were evaluated through classroom trials with 133 ninth-grade students, most of whom were either 14 or 15 years of age and hence expected to be capable of formal thought. Data were collected by means of a pretest and posttest designed for the study and through analysis of the students' responses on the self-instructional sequence. Results on the pretest showed that for the balance and inclined plane problem only 45 and 44 per cent, respectively, of the students were at the late formal stage (F2). The percentage of the sample operating at the late formal stage on the balance increased from 45 per cent on the pretest to 75 per cent on the posttest. Bass and Montague's general findings suggested that, where feasible, instructional sequences should parallel sequences of child development with respect to the subject area and endorsed further investigations on other concepts in science in order to supplement

Piaget's more general descriptions in these areas. The present investigation utilizes as one of its measures of cognitive level the Balance Problem (BP), and attempts to ascertain the role of the proportionality schema in relation to selected topics in introductory high school chemistry.

With respect to the influence of the Geneva school on science instruction and methodology it is evident that Piaget's ideas and findings have greatly affected the science curriculum and are widely used in the preparation of material, especially at the elementary science level (e.g. the Science Curriculum Improvement Study, SCIS). Further, in the area of appropriateness of specific science content, Ingle and Shayer (1971) and Shayer (1972) have described useful techniques for assessing science courses based on a close analysis of the conceptual demands in Nuffield O-level courses in chemistry and physics. In view of estimated conceptual levels in the O-level chemistry course, for example, Ingle and Shayer have made a number of suggestions for modification to the existing program which may prove effective for students of varying levels of intellectual development.

Many of the conceptual demands identified by Ingle and Shayer (1971) are seen as particularly relevant to the present study. For example, the mole concept, classified as late formal by Ingle and Shayer, and the proportions demanded in its application, is a major integrating concept to the introductory chemistry courses in the present investigation. As such, certain difficulties associated with the presentation of the mole concept and suggestions for alleviating certain teaching problems by selecting an integrating concept which

operates at a lower conceptual level, may prove useful.

One commonality associated with the numerous Piagetian studies in science has to do with the inclusion of some means whereby a measure of students' cognitive development may be obtained. This important consideration and its associated difficulties is receiving increasingly greater attention from both psychometricians and developmental psychologists (Green et al., 1971). While this attention has been directed across all developmental levels, problems associated with formal operational thought and its assessment form the focus for the present discussion.

One characterization used to describe formal thought is that of 'second degree operations'. That is, at the level of first-order relations (concrete operational thought) the child is capable of monitoring his thought processes and distinguishing between reality and the order he imposes on it. First-order operations result from the coordination of his actions upon objects but in formal thought the adolescent is able to structure relations between relations (Lovell, 1971). Inhelder and Piaget (1958) point out that propositional logic demands second-degree operations since operations are performed on statements whose content consists of class and relation operations. For example, a student cannot appreciate the necessity of holding constant those variables not being considered at the moment, unless while he is testing one hypothesis he is also aware of alternate hypotheses and their consequences. That is, he must also be aware of the second-order relations between the various hypotheses. In this sense the recognition of the equivalency of two ratios, the

proportionality schema, is a good example of a second-degree operation and any attempt at the assessment of the schema should take into consideration these second-order operations: In the present study, three of the four Piagetian tasks used, the Balance Problem (BP), the Ratio Task (RT) and the Metric Puzzle (MP) are used as measures of students' perception of the proportionality schema.

Criteria used in scoring the Piagetian tasks in the present study were drawn either from original experiments performed by Inhelder and Piaget (1958) (i.e. for the Balance Problem (BP)) or from other studies which have reported minimum criteria requirements associated with concrete and formal operational thought on these tasks (RT, MP and IP). The generic method of investigation used by Inhelder and Piaget (1958) consisted of confronting individual children with problem solving situations involving physical apparatus and recording the actions and statements of the child as he worked toward a solution. These statements were then analyzed and classified into respective stages and substages of development by Piaget. While this procedure is not always fully described, it is possible to identify minimum criteria for the classification of subjects into respective stages and substages of concrete and formal thought on the basis of the physical experiments performed in the *Growth of Logical Thinking*, Chapter V, 1958. The instructional objectives, for example developed by Bass and Montague (1972), discussed earlier, were based on Piaget's reported findings for the balance problem and the inclined plane. A frequently used scoring procedure (Lawson and Renner, 1974; Lawson et al., 1974; Friot, 1971; Field and Cropley, 1968) for the assessment of cognitive-level

based on established Piagetian task criteria consists of a four-point scale corresponding to the substages of concrete and formal thought as follows: early concrete operational - 1 point, late concrete operational - 2 points, early formal operational - 3 points, and late formal operational - 4 points. To illustrate, Lawson, Nordland and Devito (1974) used a four-point scoring scale for the balance problem developed originally from Inhelder and Piaget (1958). Scoring used was similar to that developed for the Balance Problem (BP) in the present study:

Early Concrete IIA.	S indicated lack of understanding of the relation "heavier ⇄ nearer," "lighter ⇄ farther," -- one point.
Late Concrete IIB.	S indicated understanding of the above relation however was unable to balance ten- versus five-unit weights without trial and error procedure. This indicated a lack of understanding of the simple proportion involved — two points.
Early Formal IIIA.	S was successful in achieving and explaining the balance of ten- versus five-unit weights using the concept of proportionality — three points.
Late Formal IIIB.	S was successful in achieving and explaining the more difficult balance of the seven- versus ten-unit weights — four points.

A frequently stated criticism of scoring systems like the above has to do with the misuse and unwarranted interpretation placed on the resulting student scores. That is, as the scoring procedure is based

on non-metric or ordinal data, there is little justification for treating the resulting numerical data in a manner which assumes more than ordinal qualities. In the present study, categorization of the study sample is made on the basis of a modified four-point scoring scale as follows: concrete operational - 1 point, transitional - 2 points, early formal - 3 points and late formal - 4 points. No attempt is made to differentiate between the substages of concrete operational thought and wherever possible the four point system is used only for labelling purposes. Although correlations for the Piagetian Tasks (PT) with other variables are reported (see Table V), interpretations based on the calculated correlation coefficients are made with reference to the ordinal nature of the data. Intercorrelations among the four tasks are reported in terms of the more appropriate phi coefficient (see Table III). It is interesting to note that when calculated, Pearson product-moment intercorrelations for the tasks yielded similar numerical values, preserving the rank order of the coefficients. In addition the set of four Piagetian tasks used (PT), the Balance Problem (BP), the Ratio Task (RT), the Metric Puzzle (MP), and the Islands Puzzle (IP) are administered in a group format in booklet form (Rowell and Hoffman, 1975). Student performance on the PT is made in relation to all four tasks in accordance with the modified four-point scoring system used. The criteria used for the categorization of the total study sample (N = 309) according to cognitive level, based on student performance on the PT, is presented in Chapter IV.

The following section reviews a number of studies which relate more directly to the teaching of chemistry at the high school level.

Studies Related to the Teaching of Secondary School Chemistry

Numerous studies in chemistry have been conducted which reflect Gagné's cumulative learning model. In this model Gagné proposes that the attainment of subject-matter competence is hierarchically organized. The analysis procedure used to determine intellectual skills is called 'deriving a learning hierarchy' or task analysis. For a discussion of task analysis studies related to the teaching of chemistry the reader is referred to the author's unpublished M.Ed. thesis (Wheeler, 1973).

is referred to the author's unpublished M.Ed. thesis (Wheeler, 1973).

The validity of a given learning hierarchy can be established from an analysis of the results of the administration of a test constructed to yield pass-fail information on each entity within a total hierarchy (Gagné, 1967). In order to validate the hierarchy, data on each individual rather than group data would have to be obtained. If the cumulative learning model is accurate, then any inability to perform a task should be attributable to failure on skills subordinate to it.

A limitation of task analysis is that it is initially carried out almost exclusively in the mind of the adult, and children's logic is frequently unlike adult logic. Nevertheless, a Gagné type task analysis used in conjunction with Piaget's developmental sequence could prove profitable in curriculum development. For example, in connection with the present investigation, task analysis of the components of the proportionality schema in introductory chemistry might lead to an instructional sequence designed to alleviate difficulties associated with the schema. Information regarding the nature of and relative difficulty associated with conversion, ratio, and proportionality type problems (both direct and inverse) is prerequisite to the formation of any meaningful approach to the treatment of proportionality in chemistry. However, any application on task analysis in the present study will clearly have to recognize the limitations inherent in the technique and carefully distinguish between 'facts' which are to be learned and certain 'logical operations' which must be developed. While task analysis as a tool for the curriculum designer has several built-in diagnostic features, it may be overly dependent upon certain prerequisite

mathematical skills (Okey and Gagné, 1970). While it may well be that mathematical ability is a necessary condition for the understanding of certain types of proportionality problems in chemistry, it is surely not a sufficient condition. Items on both the Chemistry Proportionality Test (CPT) and the General Proportionality Test (GPT) were constructed so as to minimize the importance of the student's mathematical abilities for the successful completion of the questions.

Studies in high school chemistry which use a Piagetian framework have been conducted by Buell and Bradley (1972) and Hall (1973). More recently Herron (1975) and Beistel (1975) have explored the implications of Piaget's work on formal operational thought to the teaching of chemistry at the freshman college level.

Buell and Bradley (1972) studied the application of a binary system in chemistry at equilibrium (temperature of solvent vs. weight of solute per 100g of water) in terms of Piaget's 16 binary propositional operations. The study was conducted with 70 high school chemistry students. Initially each student was given an Introductory Phase packet consisting of: (1) a graph of the solubilities of five salts over a temperature range and (2) a brief statement of what the graph was concerned with and a request that the student write down his interpretation of the relationships which exist on the graph and, if possible, indicate how he arrived at his conclusions. The purpose in the Introductory Phase was to ascertain at what Piagetian stage the students were, although detailed description as to the criteria used to place the students into their respective developmental stages and substages was not given.

A Directed Question Phase packet was administered after two weeks of laboratory work and discussion of solubility/temperature relations at equilibrium, in order to determine how many of the students were at the respective stages and substages of development as compared to the original categorization. The Directed Question Phase packet consisted of (1) the same graphs but with a separate table of solubilities, and (2) a series of questions concerning various concepts illustrated by the graphs.

Results of the study were somewhat discouraging. Following the two week laboratory treatment on solubility equilibria, the post-test results showed a decrease in the percentage of students attaining the formal operational stage (F2). Initially 18 percent were thought to be at the stage of late formal operations (F2) while on the Directed Questions Packet no one was considered to be at this stage. Most students (91%) were found to be at the early formal stage (F1) while only 9% were at the concrete operational stage. It was therefore suggested that contact with the realia of solubility does not improve logical thinking about constants and variables. Buell and Bradley conclude by stressing a greater need for the teaching of logical thinking in addition to manipulation of chemical glassware. However, given the lack of information supplied in the report concerning the details of the treatment and the criteria used in assessing cognitive level change, few conclusions seem justified from this preliminary investigation.

In contrast to the binary operations model, the present investigation will attempt to ascertain students' ability to perform proportional reasoning in chemistry on the basis of the interpretation placed on the INRC model.

Performance on selected Piagetian tasks will be measured according to specific criteria based on Piaget's own experimentation. Unlike the Buell and Bradley study, no attempt will be made to measure changes in the developmental stage or substage for students as a result of a treatment. Rather the focus is directed towards ascertaining difficulties encountered by students which may be related to their inability to perform proportionality problems in chemistry requiring formal operational thought.

The investigation undertaken by Hall (1973) emphasized the essential nature of conservation schemata (conservation of chemical identity, composition and mass) to the basic understanding of chemistry. Students in his sample study (N = 23, median age = 12.5) were given three experiments in which substances were heated in test tubes and allowed to cool. Subjects were told beforehand of the chemical nature of the substances and were instructed to observe carefully the changes that occurred upon heating. Following each demonstration subjects were questioned individually as follows: (1) *Do you think heating the substance turned it into a new substance?* (conservation of composition), (2) *After cooling, do you think the substance left in the test-tube is the same as the original or different?* (conservation of identity), and (3) *Do you think there was any change of weight when the substance was heated? Was the substance left heavier, lighter or the same weight as the original?* (conservation of mass). Reasons for each answer given by the individual subjects were requested and all conversations tape-recorded. Findings suggested that conservation of all three types was not attained by a considerable portion of the sample (e.g. 6 gave

nonconservation responses for conservation of weight questions). The frequencies of nonconservation responses were noted to be in the order: composition — identity — mass.

While the preliminary findings reported by Hall (1973) are subject to confirmation, they suggest that any *a priori* assumption, or at least the prospect of rapid development, of basic schemata required for the understanding of subject matter is not a justifiable one.

Hall's results indicated that even at the end of a nine month introductory chemistry course a number of basic conservation schemata were inadequately established in a high portion of the class. These findings may be related to the choice of substances for the study. Those substances selected (barium nitrate, ferric oxide and lead carbonate) all undergo rather rapid and dramatic color changes upon heating. This factor together with a complete unfamiliarization with the substances (Hall reports that none of the experiments had been encountered by the subjects previously) might have influenced their responses. Still, introductory chemistry courses might well be examined in light of Hall's findings with a view to minimizing difficulties associated with selected concepts in chemistry by facilitating the attainment of conservation concepts.

A preliminary analysis carried out by Duncan and Johnstone (1973) dealing with students' understanding of the 'mole' concept is of particular interest to the present investigation. Working at the introductory level in chemistry with 14 and 15 year old students in junior high schools in a Scottish setting, their findings suggest that considerable difficulty is encountered in understanding the 'mole' and

using it in chemical calculations.

Duncan and Johnstone (1973) and others working in the same area (Ingle and Shayer, 1971; Shayer, 1972) suggest that the major reason for the difficulties may lie with the nature of the topic and its conceptual demands which are often beyond those which the students have attained.

The four tests devised by Duncan and Johnstone dealt with: 1) Mole Quantities, 2) Calculations from Equations, 3) Molar Solutions, and 4) Reactions involving Molar Solutions. Subtests of the Chemistry Proportionality Test, CPT(2), CPT(3) and CPT(4) of the present study incorporate a number of features contained in the Duncan and Johnstone study tests. To illustrate, consider typical items used by Duncan and Johnstone dealing with straightforward 1:1 mole relationships. These presented little difficulty for the students. For example,

Item Given that

$$Mg + S \rightarrow MgS$$

What mass of Mg would react completely with 32 g of S?

(ans. 24 g)

However, when a similar item involving a non-1:1 relationship was posed, the number of students responding incorrectly rose significantly. For example,

Item Given that

$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$$

How many moles of H_2SO_4 are required to react with 1 mole of NaOH?

(ans. 1/2 mole)

Significant response features to this type of problem included a large number of students who still assumed a 1:1 relationship or who

chose the inverse relationship, i.e. 2 moles rather than 1/2 mole. Results from other similar items indicated that more than 50 per cent of the sample tended to apply a 1:1 relationship in instances in which it clearly was inappropriate. According to Duncan and Johnstone this tendency to apply 1:1 relationships to every reaction underlies much of the difficulty encountered by students in this area.

More specifically related to the present investigation several of the Duncan and Johnstone test items dealt with various chemistry problems involving proportions. Those items illustrating straightforward proportions, uncomplicated by other factors, were found to be generally well done (average difficulty = .73). For example,

Item Given that

$$C + O_2 \rightarrow CO_2$$

What mass of O_2 is required to react with 3 g of carbon?

(ans. 8 g)

Somewhat surprisingly Duncan and Johnstone also found that students had great difficulty balancing equations of the following type:

Item What is the correctly balanced form of this equation?

$$Al + O_2 \rightarrow Al_2O_3$$

(ans. 4,3,2)

Notwithstanding their findings in this regard, much greater information is needed before it can be ascertained whether the difficulties encountered are methodological in nature or stem from a more important inability to reason at a required cognitive level.

The most pronounced problem reported by Duncan and Johnstone occurred when students were confronted with an unbalanced equation

and asked to calculate from a non-1:1 relationship. For example,

Item Given that

$$N_2 + H_2 \rightarrow NH_3$$

Calculate how many moles of H_2 would react completely with 1 mole of N_2.

(ans. 3 moles)

Findings indicated that only 36 per cent chose the correct response while a large group (almost 50 per cent) chose unity as their response, indicating a reluctance to abandon the 1:1 molar relationship, discussed earlier.

Several multiple-choice items on the subtests of the Chemistry Proportionality Test (CPT) of the present study closely parallel items found in the Duncan and Johnstone (1973) study. In addition related items, devised by the investigator, involving a variety of stoichiometric relationships have been included in the CPT subtests in an effort to provide a finer analysis of student responses. Furthermore, free-response questions contained in the second section of each CPT subtest were designed to provide a more accurate assessment of students' conceptions of certain chemical phenomena. For example in relation to the 1:1 stoichiometric relationship referred to earlier, the following question assesses whether this relationship extends to a broader, 1:1 micro(atomic) - macro(molar) interpretation inherent in so much of chemistry.

Item One student maintains that the correct chemical interpretation of the reaction below is that one *atom* of A reacts with 4 *atoms* of B to form one *molecule* of AB_4.

His friend claims that a more accurate statement would would be, one *mole* of A reacts with 4 *moles* of B to form one *mole* of AB_4. Are either or both of these interpretations correct? Discuss your answer.

(equation) $A + 4B \rightarrow AB_4$

Student 1 one atom + 4 atoms → one molecule

Student 2 one mole + 4 moles → one mole

It may well be for example that students' inability to appreciate the equivalence between atomic and molar ratios is a major cause of much of the frustration and difficulty surrounding this area in introductory chemistry.

Although primarily directed towards the teaching of college freshman chemistry the work of Herron (1975) also holds considerable implication for the present investigation. On the basis of his investigations Herron maintains that in spite of available evidence indicating that approximately 50 per cent of entering college students are unable to function at the formal operational level, both the content of chemistry and the manner in which it is presented requires that the student operate at the formal level if he is to truly comprehend the concepts covered. If Herron's assessment is correct then the problem, by extrapolation, may be even more acute at the introductory high school level.

The danger in not recognizing that a large portion of students may not be operating at the formal operational level may be to penalize those "good" students who do make a conscientious effort to learn but are limited in their achievement by their stage of intellectual development. For example, Herron found that students who had learned to calculate density from mass and volume data were frequently unable to answer such questions as: *Water has a density less than that of sulfuric acid. Which would have the greater volume, 100g of water or 100g of sulfuric acid?* Or in another instance, home economics majors were asked to explain the difference between the representations H^+, H and H_2.

Although a few students were able to attach a name of ion, atom and molecule to the three, none of the students questioned seemed to have any conception of the difference in the particles represented.

The significant relationship (r = 0.8. N = 17) found by Herron between achievement in college freshman chemistry and cognitive level as measured by a battery of Piagetian tasks reinforces the need to recognize the importance of this dimension in the teaching of chemistry. While not denying the formal, abstract nature of much of chemistry, Herron suggests two ways in which the problem may be alleviated. One can skirt the problem by trying to make what is taught in chemistry accessible to those students who are not formal thinkers or one can overcome the problem by encouraging and assisting students in becoming formal thinkers.

With regard to making the content of chemistry more accessible to the concrete thinker, Herron has identified examples of certain performances in chemistry which he feels can be performed by students who are not formal in their thinking. Table I presents those competencies which are pertinent to the present investigation together with descriptions of related performances which require formal thought.

Herron points out that his list of competencies represents only hypothesized differences and is based on the author's judgment of the mental activity required to accomplish the task. To date no tests have been devised to establish whether concrete operational individuals can perform the tasks indicated on the left or that the tasks on the right can only be performed by formal operational individuals. The present investigation dealing with competencies related to the proportionality

TABLE I

Competencies Commonly Expected of General Chemistry Students Which Can Be Understood by Students Who Are Not Formal Operational

Things that students who have not reached formal operations CAN DO	*Things that students who have not reached formal operations CANNOT DO*
1. Comprehend the idea that the ratio of the mass (or volume) of hydrogen to the mass of oxygen in water is constant. (This should be in the 'can do' list only if the idea is developed from actual observation of data or through a procedure which enables the student to understand the source of the data.)	1. Reason that the constancy of mass ratios and volume ratios in substances such as water leads to a conclusion that compounds can be represented as particles made up of atoms combined in definite proportions.
2. From the definition of Molarity prepare 1000 ml of a 1M solution.	2. From the definition, prepare 25 ml of a 2.5M solution. Prepare 1000 ml of 0.25M solution from a 3M stock solution.
3. Follow a set of rules to find the empirical formula of a compound.	3. Understand why following the rules will result in the empirical formula.
4. Conceive of atomic weight as the mass of a given number of molecules, i.e. the atomic weight is the weight (mass) of 6.02 x 10^{23} atoms.	4. Conceive of atomic weight as the ratio of the mass of one atom to the mass of some other atom which is selected as standard.
5. Use factor-label to solve problems in instances where the units provide an indication of the operations to be performed.	5. Use ratio and proportions to solve problems which will not fit into a 'type' problem which has been memorized.
6. Balance equations, write formulas, calculate molecular weights, etc., using set rules.	6. Derive the rules for balancing equations, writing formulas, etc. from general principles such as Law of Conservation of Mass, or the Law of Definite Proportions.

schema will test for the hypothesized differences between selected competencies as postulated by Herron. For example, in the present study the performance of students employing a dimensional analysis (i.e. unit analysis or factor-label) approach to proportionality problems in chemistry will be compared with those taught in a more traditional ratio and proportion manner. Here the hypothesis is that in order for a student to consistently apply the ratio and proportion approach to chemical problems correctly he must be capable of formal thought. However, in the areas of both gravimetric and volumetric stoichiometry, dimension analysis should provide an almost infallible procedure for solving such problems correctly without the necessity of formal thought. At the same time dimension analysis organizes the chemical facts in a given problem in such a manner that it may lead the students to see the reasoning that characterizes the solution leading to greater understanding. However, as pointed out by Herron (1976, mimeo), caution is advised in the use of dimension analysis as one may encounter certain other problems related to closure.

In connection with the present investigation, findings concerning the importance of closure for concrete thinkers contain a number of direct implications. For example, if as found by Collis, non-formal students do not perceive indicated products such as (2 x 3) as names for numbers, then expressions such as 6.02×10^{23} or 1.66×10^{-24} in chemistry will undoubtedly cause great difficulty. Instead of viewing the expressions as numbers in themselves, non-formal students treat such expressions as indicated operations which *would yield* numbers only if they were carried out. Certain items on both the Chemistry

Proportionality Test (CPT) and the General Proportionality Test (GPT) in the present study are designed to study the relationship between cognitive level, response approach and achievement.

It may be misleading to maintain that a student who is not formal in his thinking can truly 'understand' the conceptual structure of chemistry. The contention that the absence of formal operational structures places restrictions on the ability of students to learn certain concepts has been termed the 'idea of intellectual structural limitation' (Hobbs, 1975).

Proponents of the idea of intellectual structural limitation suggest that, in view of the high percentage of secondary school students who are not formal operational (Lawson, 1973), it is imperative to adopt an instructional approach which constantly allows students to interact with concrete objects and situations. One implication of the idea of intellectual structural limitations for the science teacher is that he should be constantly exploring means to make the subject matter more 'accessible' to the learner. The dimension or unit-analysis approach to stoichiometric problems discussed earlier is an example of such an approach in chemistry.

An inherent danger in any allegiance to the idea of intellectual structural limitations is a tendency to avoid responsibility in developing formal reasoning in students. The failure, for example, to recognize that chemistry is by its very nature formal and to a large degree abstract may lead to teachers reducing their efforts toward the development of formal thought in their students. The search for alternative approaches which rely to a lesser extent on formal

operations than do present treatments is not enough. The development of formal thought should be a major responsibility of the teacher.

The analysis of the formal operational schema of proportionality in the present study may suggest means whereby the intellectual development of students may be enhanced. For example, information regarding the hierarchical nature of the components of the proportionality schema may prove useful in promoting a shift towards formal operational thought. According to Beistel (1975) the ordering of topics presently found in several introductory chemistry texts does little to promote formal thought, often thrusting the concrete operational student far beyond his intellectual level from the beginning of the first semester. Beistel (1975, p. 152) presents a suggested list of topics in introductory chemistry that recognizes that not all students are formal operational and assists the concrete operational student to become formal under the guise of review. In addition Beistel contends the 'mole concept' can prove useful as a unifying theme for a beginning course in chemistry. Revisiting the mole concept from a variety of approaches at different times maximizes the opportunities for learning the concept. This technique may be a crucial factor in the ability of students to apply the concept in a variety of situations. Items on the Chemistry Proportionality Test (CPT) used in the present study measure students' perceptions of the varied transformations embodied in the mole concept.

Studies Related to the Proportionality Schema

A number of research studies relating to proportionality have been carried out over the years. One of the earlier studies was that done by

Cowley (1937). More recently Karplus and co-workers have investigated the development of the concepts of ratio and proportion in several studies (Karplus and Peterson, 1970; Karplus and Karplus, 1972; Karplus, Karplus and Wollman, 1974; Wollman and Karplus, 1974). Other researchers, notably Lovell and Butterworth (1966), Lunzer and Pumfrey (1966) and Lovell (1971), have studied the development of proportional reasoning using a wide variety of approaches. In general, all studies have confirmed the slow growth of the schema even at the high school level. Although several studies categorized students on the basis of proportional reasoning, the tasks used were not directly related to chemistry or to the students' current science curricula.

Cowley (1937) investigated high school students' grasp of the relationship of measurable quantities as revealed by their comprehension of ratio and proportion. Analysis was based on an examination of the treatment of ratio and proportion in high school textbooks of mathematics, physics, and chemistry and a 10-item questionnaire administered to approximately 2000 students studying chemistry or physics at the high school level. Results of the questionnaire revealed that the majority of students in the sample had a weak grasp of ratio and proportion expressed in terms of everyday affairs (mean difficulty level of the items was 0.54). Cowley suggested that many of the difficulties encountered by students arose because they tended to view proportion as merely a mechanical device governed by purely arbitrary rules. The chemistry texts examined by Cowley revealed a number of inconsistencies in the method of writing proportions, examples used to illustrate direct and indirect (inverse) proportionality and the treatment of

calculations from chemical equations were noted.

Cowley points out that the method of writing a proportion may seem to be a trivial matter but thoughtful attention soon leads to the conclusion that the 'symbolism' is of real importance. If, for example, a proportion is written as a fractional equation, it is at once associated in the mind of the student with fractions. The student may realize that changes in either the numerator or denominator alter the value of the fraction but that certain changes made in both leave the value unchanged. However, if a proportion is written a:b::c:d and read as "a is to b as c is to d," the student may not see the connection with anything he already knows.

Problems dealing with chemical calculations from equations rely heavily on the students' ability to understand the equivalency of various ratios contained within it. Writing a proportion as a fractional equation may more readily enable the student to perform certain transformations necessary in solving such problems in chemistry. In the present investigation the type of symbolism used in solving proportionality problems in the area of stoichiometry will be analyzed to determine the relative effectiveness of the two commonly used approaches to the area.

The series of studies conducted by Karplus et al. has provided considerable information on the ability of students at both the concrete and formal levels of thought to apply proportional reasoning to a number of tasks. The initial study (Karplus and Peterson, 1970) dealt with students' ability to apply proportionality to a problem requiring a change in the unit of length measurement. In the task,

labelled "Mr. Short," students were provided with answer pages containing a scale drawing of "Mr. Short" and a number of small paper clips. Subjects were then shown a display chart with the same figure on their pages on the front side and a scaled up version of the figure on the back, referred to as "Mr. Tall." With the subjects watching, the experimenter measured the two figures using large paper clips (the small and large figures were constructed so as to measure four and six jumbo paper clips, respectively). Subjects were then asked to measure Mr. Short on their papers, using small clips, predict the height of Mr. Tall in terms of small clips and explain how they arrived at their prediction. A total of 727 subjects, ranging from age 9 to 18 years and covering grades four to twelve in both suburban and urban schools, were administered the task in a group setting and written responses to their solutions were collected.

Categorization of the subjects' explanations yielded the following categories:

Category N: (Intuition) - an explanation referring to estimates, guesses, appearances, or extraneous factors without using the data.

Category IC: (Intuitive computation) - the subject utilizes the data haphazardly and in an illogical way.

Category A: (Addition) - an explanation using all of the data but applying the differences rather than the ratio of measurements.

Category S: (Scaling) - the subject utilizes a change of scales when predicting but does not relate this operation to the scale inherent in the data and thereby fails to see the whole problem.

Category AS: (addition and scaling) - the subject focuses on the excess height of Mr. Tall, but scales up the excess number of large clips by a factor of two to compensate for the size difference.

Category P: (Proportional reasoning) - the subject uses proportionality and makes clear how the ratio is derived from measurements on the two figures. He may or may not use the word 'ratio'.

Results clearly indicated that the older children were better able to solve the ratio problem than were their younger colleagues. However, it was found that the suburban subjects achieved substantially higher on the task by the end of high school than did the urban students (i.e. for grades 8--10, 32% of the suburban students were found to exhibit proportional reasoning [Category P] compared to only 5% of the urban students). No explanation for this discrepancy was offered. Results of the categorization of students were inconclusive with respect to revealing any developmental sequence in terms of Piaget's theory. While Category I (intuitive) clearly represented the most naive approach (pre-operational) and Category P the most sophisticated (formal), the other groups could not be serially ordered into any logical single sequence. It was felt that Categories IC, A and S might form one possible sequence while Categories S, AS and P might represent another. In fact, the authors suggest a student might progress through either one of these sequences.

In order to gain further insight into any developmental sequence exhibited by the subjects' responses, Karplus and Karplus (1972) administered the same task to 155 sixth, eighth and eleventh grade suburban students who had been tested two years previously as fourth, sixth, and ninth graders. In general, results of the longitudinal study agreed favorably with the earlier study (Karplus and Peterson, 1970) and reflected a certain degree of stability as to the basis of categorization. More than one third of the total students tested

showed no change in category over the two year period. Changes that did occur indicated that Categories AS (addition and scaling) and P (proportional reasoning) were more advanced than the others (addition [A] and scaling [S]) since 36 students (28% of those in other categories) moved into AS or P, while only one student (4% of those in AS or P) moved out of P to A.

On the basis of their longitudinal data, Karplus and Karplus suggested grouping the categories into the three developmental stages as described by Inhelder and Piaget (1958). Level I (pre-operational) would include Categories I and IC, Level II (concrete operational), Categories A and S, and Level III (formal operational), Categories AS and P. The formal level categories, AS and P, were considered to represent the respective substages of Level III: AS corresponding to early formal thought (Level IIIA) and P representing formal thought (Level IIIB) insofar as proportional reasoning is concerned.

Because of the somewhat unclear nature of the Categories S (scaling) and A (addition), there appeared little justification in placing these categories into substages at the concrete operational level. Evidence to determine whether the Categories A and S were alternate or sequential was inconclusive. Eight of the 39 students originally in either of the two categories moved to the other one over the two year span. The authors suggested that these categories may represent a 'metastable operational equilibrium,' with many students changing from one category to the other and then back again to the original category during the two years between testing.

A later study conducted by Karplus et al. (1974) used a new form

(Form B) of the original paper clip ratio task (Form A). In Form B, administered to 616 students in grades 4 to 9, subjects were not shown the measurement of both figures. Form B subjects were deprived of actually seeing Mr. Tall and were only told of his height (this time in terms of buttons). The ratio of the heights of the two figures (6:4) remained constant for both forms of the task. Results of the categorization of subjects on Form B revealed an exceedingly small fraction of responses in the S (scaling) category, a category which had included about one-third of the responses on Form A. Frequencies of responses increased in categories which required conceptual processing of the data (e.g. addition) and P (proportional reasoning).

A substantial fraction (between 30 and 40 per cent) of subjects on Form A appeared to provide an explanation which was derived principally from perception rather than reliance on data measurements. On Form B, where subjects were deprived of the opportunity to observe the large figure and the large clips, subjects did use the data with varying degrees of success. Karplus was therefore led to conclude that the intuitive and scaling responses to Form A (Categories I and S) may reflect the individual's cognitive style rather than a developmental sequence in the Piagetian sense. However it should be noted that any relationship between cognitive style and performance on these tasks is on the basis of evidence provided, purely speculative. It may well be, for example, that the effect of changing the format in the two forms of the task (Form A and Form B) was to remove much of the initial ambiguity in interpretation of the instructions present in Form A.

The Form B ratio task was considered more satisfactory for studying cognitive development as it compelled subjects to make use of the

data. While little can be said of the influence of conceptual style on students' performance on the basis of this study, it does point out the importance of the specific nature of any task presentation in future investigations of this type.

To gain further insight into the generality of formal thought, Wollman and Karplus (1974) studied the responses of 450 seventh and eighth grade students to six problems which required proportional reasoning and which presented varying degrees of concreteness. Four of the tasks required students to make inferences and to provide an explanation of their reasoning. These included the Paper Clips Form B task, a Candy task, a Ruler task and a Pulley task. Three geometrical items and four numerical items were also administered using a short-answer paper-and-pencil format to further extend the range of situations faced by the students.

The four tasks chosen varied in their level of 'concreteness', with the Paper Clips Form B task and Ruler task considered to be the most concrete. While the Pulley task included concrete aspects it was intended to be more difficult and to challenge subjects who used proportional reasoning on other tasks. The Candy task, involving prediction of the color composition of bags of candies (red candies and yellow candies) given certain information, was considered the most abstract. According to the authors all tasks in the study were devised to apply the ratio and proportion concept in familiar or easily imagined situations and were independent of the understandings of certain scientific principles, i.e. the law of moments, light propagation, etc. The geometrical items were presented in pictorial form rather than in

numerical form and were similar to exercises commonly found in mathematics texts. The numerical items presented information in purely abstract form-number pairs out of context. They were included to test subjects' ability to apply proportional reasoning with no circumstantial clues and resembled items used by Lovell and Butterworth (1966).

With minor modifications the categories used in the Paper Clips task were adapted for use in the Candy, Ruler and Pulley tasks. As the geometrical and numerical items did not require explanations, they were evaluated solely in terms of the accuracy of responses. In general, results of the extensive collection of data in the study indicated that there was a lack of generality of proportional reasoning over the six tasks. For example, only eight students consistently showed proportional reasoning on each of the Paper Clips, Ruler and Pulley tasks. On the more abstract Candy task, a large number of students used additive reasoning rather than advancing to one of the subcategories of proportional reasoning. As expected, in tasks where concrete aspects existed (as in the geometrical items, the Ruler task and the Paper Clips task), more students answered the questions successfully than for the more abstract tasks. Overall, about one-fifth of each group tested applied proportional reasoning at the formal level consistently on several tasks. Approximately one-fourth of each group applied proportional reasoning at the formal level on some of the tasks but not on others and numerous incorrect additive strategies were used by many students on several tasks.

The series of tasks and studies conducted by Karplus and his co-workers suggest a number of considerations for the present investigation

into proportional reasoning in chemistry. First from a methodological point of view, the group administration of tasks requiring subjects to write down their responses has been shown to be a viable approach in this area. The present study uses tasks in both a chemical and non-chemical context administered in group format. The categories described by Karplus, especially the subcategories of concrete and formal thought, may prove useful as a basis for categorization of subjects in the present study.

Results of the Wollman and Karplus (1974) study are consistent with earlier findings with respect to the difficulty associated with proportionality problems as reported by Lunzer and Pumfrey (1966) and Lovell and Butterworth (1966). Lunzer and Pumfrey reported that the majority of children were able to make successful predictions using Cuisenaire apparatus for all ratios by the age of nine. Their study which used a number of approaches, rods, a pantograph, balance beams, sets of number pairs, etc., revealed that true proportional reasoning unaccompanied by physical actions was rarely used by average subjects below age fifteen. Like the large number of subjects categorized as Category A (addition) by Karplus et al., Lunzer and Pumfrey found that children at all ages seem to prefer additive modes of solutions even when the problem could suggest multiplicative methods. That is, in attempting to establish a relation between relations, the unsuccessful student prefers to add and subtract, and perhaps multiply but seldom divide. Although students' explanations involved using all of the data, as many as 50 per cent of subjects on some tasks merely applied the difference between measures rather than the ratio of measurements. Lunzer and Pumfrey concluded

that although students had learned multiplication and division, they did not really appreciate the inverse relationship between them.

The study performed by Lovell and Butterworth (1966) on the abilities underlying the understanding of proportionality involved 20 tasks, some of which did not relate to the schema of proportion. The tasks included number analogies, the balance experiment, and the Rings and Shadow experiment (Inhelder and Piaget, 1958), the relation between the size of the external angle of a regular polygon and the number of sides of the polygon, verbal analogies, money problems, rate and time problems (both direct and inverse proportion), and ratios of the areas of similar triangles. A principal-components analysis performed on the intercorrelation matrix for the tasks showed that a marked general factor was in evidence which correlated highly with tasks involving the proportionality schema. For example, of the five tasks which had loadings greater than 0.7 on the general component, the task which involved calculations of the missing numbers, i.e.

$$\begin{array}{cc} 16 & 12 \\ 8 & 6 \\ 10 & 7.5 \\ ? & 9 \end{array}$$

received the highest factor loading (0.84). As pointed out by the investigators, this was not unexpected as this task was the clearest type of exercise involving the equivalence of two ratios. Other tasks used to characterize the general factor included the two Piagetian experiments (Balance, and Rings and Shadows), ratio of the areas of similar triangles, polygon problems and verbal analogies. Lovell and Butterworth further noted that tasks involving ratio only depend less on the general ability than those tasks involving proportion. For example, a loading of only 0.47 on the general factor was obtained for

the task requiring students to calculate the ratio of the volume of cuboids given the dimension of the cuboids.

In addition to the central intellectual ability factor, Lovell and Butterworth also found considerable variation in the level of performance of subjects across the tasks. This led them to conclude that certain specific abilities contribute to the ability to use proportionality in particular tasks. That is, the proportionality schema did not appear to be available in all situations and tasks at the same time. In the present study an attempt will be made to ascertain the extent to which proportional reasoning is applied in a chemical context as compared to more general tasks involving proportionality. Section II of the General Proportionality Test (GPT) used in the present context includes examples of items that received high loadings on the general factor underlying proportionality as reported in the Lovell and Butterworth study. Items on the GPT include verbal questions and numerical questions involving ratio and proportion.

The studies reviewed suggest that the understanding of the proportionality schema is a complex problem involving several factors which need to be studied from both a psychological and methodological point of view. While several studies have dealt with proportionality in a variety of content areas, no one has yet investigated the role of the schema longitudinally within current science curricula. Although the late acquisition of the schema has been substantiated (Lovell, 1972), comparatively little information is available on the developmental aspects of proportionality and the specific difficulties encountered by students in the classroom setting. Such difficulties may be related

to cognitive level, approach taken and specific content studied. The nature of the present investigation, by focusing on all three above variables, represents an in-depth analysis of the proportionality schema in introductory high school chemistry.

Chapter III

INSTRUMENTATION AND PROCEDURE

The role of the proportionality schema in introductory chemistry is the central focus of the present study. A detailed explanation of the schema as it relates to selected areas of high school chemistry and the instruments constructed to measure it form an important part of this chapter. In the first section the four preliminary investigations conducted prior to the main study are discussed. The second part of the chapter embodies the details of the design of the study including sampling, test construction and testing procedure.

Preliminary Investigations

Four related pilot projects involving the two forms of the General Proportionality Test (GPT), the set of Piagetian Tasks (PT), and the four subtests of the Chemistry Proportionality Test (CPT) were conducted prior to the formal administration of the test instrument to the main study sample. As a standardized chemistry achievement test was made available to the investigator by the Testing Division of the Edmonton Public School Board, no preliminary testing of the Chemistry Achievement Test (CAT) was undertaken. A brief discussion of the approach used in the preliminary investigation of each of the above instruments follows:

i) *General Proportionality Test (GPT)*

An initial single form of the GPT was distributed to twelve experienced secondary science teachers, professors and graduate students in science education in order to assess its accuracy, clarity, degree of

difficulty and relevance to its intended purpose. The decision was made at this time to attempt to construct two logically equivalent forms of the test, GPT(Form A) and GPT(Form B) in order to allow for the assessment of both pre- and posttest student performance on this instrument.

The test format for both GPT forms was identical and consisted of the following type questions:

i) 3 dummy items (Q 1-3)
ii) 2 conversion-type items (Q 4,5)
iii) 2 ratio type-items (Q 6,7)
iv) 4 direct proportionality-type items (Q 8-11)
v) 3 inverse proportionality-type items (Q 12-14)
vi) 1 combined proportionality-type item (Q 15).

After incorporating other more minor changes deemed necessary by the consultants the GPT was administered during May 1975 to two classes of Grade 9, Grade 10 and Grade 11 students (N = 155) in order to further refine the instrument. One class at each grade level was given one form of the GPT while the other was administered the alternate form.

A more detailed discussion of these proportionality type items in the GPT is presented in a later section of this chapter.

Results of the preliminary testing served to establish the degree of reliability of the two forms of the GPT. Minor format changes together with the rewording of several items in accordance with terminology more consistent with the curriculum were also taken at this time. The decision to include an additional section in the instrument consisting of items which were found by Lovell and Butterworth (1966) to correlate highly with tasks involving the proportionality schema was also taken at this time. Certain verbal reasoning type questions were also included in this additional section in an attempt to further discriminate between those students operating at the concrete and formal

operational levels of cognition.

Revised forms of the GPT were administered to a sample (N = 216) of students in Grades 7 to 11 inclusive during the 1975 fall semester term. Results of this investigation provided the basis for several further minor modifications in the GPT forms. In order to ascertain whether or not the forms were statistically equivalent, an analysis was conducted on the basis of the preliminary testing results. These are presented and discussed in a later section of this chapter dealing with the GPT.

Changes included rewording of certain items together with varying the position of the keyed response to each item so as to avoid any consistent pattern. In addition certain numerical series questions were replaced and a section added which required students to give a written explanation for their answer in each case. The revised forms, GPT(Form A) and GPT(Form B) are presented in Appendix A. Items in the first section of each GPT form corresponding to particular proportionality types are included in Appendix F.

ii) *Piagetian Tasks (PT)*

The major objective of piloting the four Piagetian Tasks was to produce a workable group form of the tasks which could be used to provide a measure of the current cognitive functioning level of the students. Initial consultation with Piagetian experts resulted in replacing one of the originally proposed tasks because of the inappropriateness to the focus of the present investigation. Construction of the tasks chosen for inclusion in the pilot test booklet closely followed criteria used in the balance problem (Inhelder and Piaget,

1958) and those used in other investigations, namely the Ratio Task (Form B) (Karplus and Karplus, 1972) and the Islands Puzzle (Karplus and Karplus, 1970). An additional task devised by the investigator, the Metric Puzzle, was also included in the test booklet. The Piagetian tasks were then group administered to a Grade 10 and Grade 11 sample of chemistry students (N = 50) during the 1975 fall semester. Results of the testing support the finding of Rowell and Hoffman (1975) who maintain that it is possible to translate some Piagetian problems into a reliable group form for ease of administration and assessment. Given the intended purpose of the Piagetian indicators in the present investigation, the group approach appeared to be a viable one in the present context.

The Piagetian Tasks in booklet form are presented in Appendix B, together with the criteria used in assessing student performance on these tasks.

iii) *Chemistry Proportionality Test (CPT)*

The four subtests of the CPT deal with the following topics in introductory high school chemistry: a) nomenclature and the writing of formulae, CPT(1), b) chemical reactions, CPT(2), c) the mole concept, CPT(3), and d) gravimetric stoichiometry, CPT(4). Development of the subtests of the CPT took the following general course:

1. An initial draft of the subtest was prepared by the investigator based on an analysis of the ALCHEM Materials* covering the topic

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*ALCHEM Materials refers to the Alberta Chemistry Project Materials developed for high school chemistry by Edmonton School District #7. Copyright, 1975. Units relevant to the present study appear in Appendix G.

in question. Those aspects dealing directly with the proportionality schema were incorporated into the instrument. Several items not directly related to the proportionality schema were also included in each subtest in an attempt to have each subtest more realistically conform to the unit of study covered. Drafts of particular subtests of the CPT were distributed to the four science teachers cooperating in the pilot investigation for their comments.

2. Following revision and feedback from the practising science teachers, a second draft of each subtest was constructed incorporating those changes deemed necessary by the consultants. Considerable revision occurred at this stage including the complete deletion of questions, rewording of items and adjustment for writing time. These revision sessions also produced a number of questions and suggestions for subsequent subtests of the CPT.

3. An initial form of each CPT subtest was administered by the cooperating teachers to the six Grade 10 classes (total N = 119) following the conclusion of instruction of the appropriate topic during the 1975 fall semester. Students were informed beforehand that results of each subtest would serve as part of the regular classroom evaluation in the chemistry course. Following suggested revisions by the cooperating teachers and results of an item analysis on each subtest of the CPT, a final draft was constructed. The general format for the CPT subtests incorporated two main sections. Section 1 is composed of multiple-choice, machine-scored items dealing with those aspects of proportionality pertinent to the topic. Parallel types of items as those found in the General Proportionality Test (GPT) (e.g. conversion,

ratio and direct proportionality type questions) are included in this section. The second section consists of short answer, more open-type questions involving proportional reasoning in chemistry for which students are required to explain their responses.

Final version of the four CPT subtests, CPT(1), CPT(2), CPT(3), and CPT(4) are presented in Appendix C. Items on the subtests corresponding to particular proportionality types are indicated in Appendix F.

The Sample

The total sample for the study consisted of 309 students enrolled in Chemistry 10 programs in three high schools of the Edmonton Public system and one high school in the Edmonton Separate system. A total of twelve classes and ten teachers were involved during the 1976 winter semester.

The main study sample (N = 168) consisted of seven ALCHEM Materials classes in two Edmonton Public high schools. Four of the five CHEM Study classes (N = 141) were drawn from the Edmonton Separate system. Each of the seven cooperating ALCHEM classes was taught by a different teacher, while two cooperating CHEM Study teachers each taught two classes. The remaining CHEM Study class was taught by one teacher in a large composite public high school.

While all preliminary testing of the Chemistry Proportionality Test (CPT) was conducted on students using the ALCHEM Materials Program, the major purpose of the investigator was towards the more general role of the proportionality schema in introductory high school chemistry. As CHEM Study is a much more widely used and recognized chemistry

program, it was incorporated into the study design for comparative and generalization purposes. Those topics covered by the CPT subtests are common to both CHEM Study and the ALCHEM Materials Program.

Given the nature and demand of the testing procedure, a volunteer teacher approach was used in obtaining cooperating classes rather than a random selection of classes for inclusion in the main study sample.

Test Construction

Four main test instruments were used in the study:

i) *Chemistry Achievement Test (CAT)*: A 60-item multiple-choice, 4 distractor open book general achievement test based on the Chemistry 10 program. The CAT first formed the Chemistry 10 final examination for the Edmonton Public schools in January 1975. Items on the CAT were drawn from a pool of some 400 items for which item statistics are available. The CAT deals with all major topics in the Chemistry 10 core program and includes items equivalent to those present on the subtests of the Chemistry Proportionality Test (CPT), e.g. chemical nomenclature, chemical reactions, mole concept, and gravimetric stoichiometry.

ii) *General Proportionality Test (GPT)*: The two forms of the GPT (Form A and Form B) deal with ratio and proportion as they are applied in common situations. Form A and Form B were constructed to be logically equivalent in both the format and type of proportionality question found in each. In order to assess whether the two forms of the GPT were equivalent in a statistical sense, t-tests were performed on the basis of preliminary data collected during the 1975 fall semester term. Two classes in each of Grade 9, Grade 10 and Grade 11 (N = 155) were each administered either Form A or Form B of the GPT.

Calculation of t-tests revealed non-significant differences between the means of GPT(A) and GPT(B) for Grades 10 and 11 ($p > .20$). The difference between means for the Grade 9 sample was found to be significant at the 0.05 level ($t = 2.24$, $df = 51$). However, as one Grade 9 class was noted to be academically weak in other subject areas, little emphasis can be placed on the significant result encountered on the basis of this sample. In view of the intended nature and level for which the GPT was designed there appeared to be support for the statistical equivalence of the two forms of the instrument.

The first section of both forms of the GPT consists of multiple choice items dealing with the following aspects of the proportionality schema.

1) *Conversion problems.* While not necessarily employing ratio or proportion directly, conversion type problems require students to perform a transformation or reduction on given data to yield a required result. This alteration may take the form of a simple conversion (e.g. inches to centimeters) or more commonly to problems where the conversion yields a more interpretable form,

> e.g. A family of four reports that their monthly food bill is $150.00. What would the year's food cost for this family be?

It should be noted here that the conversion type problems, as used in the study, may be viewed as a special case of proportionality involving unity. That is, in the above example, the proportionality expression, $\frac{150}{1} = \frac{X}{12}$, could be used to obtain the correct answer.

2) *Ratio problems.* This type of problem involves the ability to recognize and compare ratios as applied to a number of common situations.

Items dealing with ratios require students to understand the fixed relation between or among quantities and numbers and may or may not involve the reduction of given ratios to simpler forms.

> e.g. An electronic parts assembler, Tom, is able to produce 4 complete units in 20 minutes. A second worker, Bill, assembles 3 similar units in 18 minutes. Who works faster, Tom or Bill?

3) *Direct proportionality problems.* Proportionality items of this type deal directly with the quality of ratios and require the understanding of the direct relation among quantities such that the quotient of the first divided by the second equals that of the third divided by the fourth. Normally students set up a proportionality expression based on the given data and solve for the required unknown.

> e.g. A recipe for orange punch requires that 5 cups of orange juice be mixed with 8 cups of water. How many cups of orange juice are needed to make 52 cups of punch?

As noted earlier, this type of problem is not unlike the conversion problem where proportionality expression is solved to yield the desired answer (in this case the expression is given by $\frac{5}{13} = \frac{X}{52}$).

4) *Inverse proportionality problems.* Although similar to the above proportionality items, this type deals with proportionality as it relates to inverse (or indirect) relationships among quantities as applied to common situations.

> e.g. Five men build a large pre-fab house in 10 days. How long will it take 15 men, of equal capability, to build an identical house?

The second section of the GPT consists of questions related to ratio and proportion and includes:

1) *Verbal questions.* Items of this type include both verbal

analogy questions and items measuring verbal reasoning. Lovell and Butterworth (1966) found that verbal questions of this nature loaded highly (0.7) on a general factor they identified as being strongly related to the proportionality schema.

e.g. Toe is to foot as *finger* is to hand.

e.g. Joe is taller than Bill, Joe is shorter than John. Who is tallest of the three?

2) *Numerical questions.* These items include numerical questions involving ratio and proportion dealing with arithmetic and geometric series that can be solved by multiplication or division by a whole number. In addition items are included which deal with the calculation of missing numbers and numerical analogies.

e.g. 7 2 14 3 21 4 _____

e.g. 1 9 25 49 _____

e.g.	5	13		2	8
	7	17	and	4	64
	4	11		3	27
	6	?		5	?

e.g. 100 is to 10 as 400 is to _____

iii) *Chemistry Proportionality Test (CPT)*: A test devised for the study of short answer questions in introductory chemistry in which students are required to show all their work in arriving at their solutions. The CPT is composed of four subtests each one dealing with one of the following topics:

a) *Chemical nomenclature and the writing of formulae* (CPT(1)).

e.g. Given two hypothetical elements X and Y with valence +6 and -2 respectively, suggest a formula for the compound formed between X and Y.

b) *Chemical reactions* (CPT(2)).

e.g. Write a balanced chemical equation from the statement: Aluminum sulphide reacts with water to form aluminum hydroxide and hydrogen sulphide.

c) *The 'mole' concept* (CPT(3)).

e.g. Determine the number of moles in an 80g sample of NaOH (1 mol = 40g).

d) *Gravimetric stoichiometry* (CPT(4)).

e.g. Given a balanced chemical equation represented by $aA + bB = cC + dD$ where a, b, c, and d represent the numerical coefficients of the substances A, B, C, and D, students are asked to calculate, for example, the number of moles of B required for complete reaction with X moles of A.

The items on the CPT subtests were constructed so as to illustrate chemistry aspects of the proportionality schema analogous to those found in the General Proportionality Test (GPT). For example:

i) *Conversion type problems.*

e.g. Find the number of atoms in 16 g of sulphur (at. wt. of S = 32)

ii) *Ratio type problems.*

e.g. Determine the reacting ratio of two substances in a given balanced chemical reaction.

iii) *Direct proportionality problems.*

e.g. Given that one mole of any element contains 6.02×10^{23} atoms, calculate the weight of *one* atom of oxygen (at. wt. of oxygen = 16).

iv) *Piagetian Tasks*

These refer to the following paper-and-pencil tasks used in the present study:

a) *Balance Problem (BP)*: (Inhelder and Piaget, 1958; Lovell, 1961; Lunzer and Pumfrey, 1966).

b) *Ratio Task (RT)*: a modification of the Form B paper clip ratio task used by Karplus et al. (1974) described in an earlier section.

c) *Metric Puzzle (MP)*: a direct proportionality task requiring students to predict a distance in kilometres given basic data necessary for the conversion. The Metric Puzzle is a modification of that used by Collea, 1975.

d) *Islands Puzzle (IP)*: a paper-and-pencil formal operational task requiring students to answer questions concerning possible plane routes among a series of four islands, given certain constraints.

The set of Piagetian Tasks (PT) are presented in booklet form in Appendix A.

Testing Procedures

At the beginning of the 1976 winter semester, all Grade 10 chemistry students cooperating in the main study were administered one form of the General Proportionality Test (GPT). Prior to the commencement of any instruction in chemistry, the set of Piagetian Tasks (Balance Problem, Ratio Task, Metric Puzzle and Islands Puzzle) were administered collectively during regular classroom periods. The four subtests of the Chemistry Proportionality Test (CPT) were administered by cooperating teachers following the conclusion of each appropriate unit of instruction during regular classroom periods throughout the 15 week semester period. At the conclusion of the term, all students in the sample were then given the Chemistry Achievement Test (CAT) as part of their regular classroom evaluation in chemistry. At this time all students in the sample were also administered the alternate equivalent form (either Form A or Form B depending on the initial assignment) of the General Proportionality Test (GPT).

For a given class in the main study the basic design could be represented as:

	Pretest					*Posttest*
Class A	GPT (A) PT	CPT(1)	CPT(2)	CPT(3)	CPT(4)	GPT (B) CAT

No direct attempt was made in the investigation to control for instructional variables within the two basic instructional approaches identified for inclusion in the study. As such the design of the investigation does not represent a true experimental approach to the problem. Rather, the emphasis was viewed more as the identification and descriptive investigation of problems associated with proportional reasoning in introductory high school chemistry which may yield practical implications for the classroom teacher.

Chapter IV

RESULTS AND DISCUSSION

Introduction

The results of the study are presented and discussed in this chapter. The chapter is organized into four major sections. The first section presents the findings with respect to the Piagetian Tasks (PT), the two forms of the General Proportionality Test, GPT(Form A) and GPT(Form B), the four subtests of the Chemistry Proportionality Test, CPT(1), CPT(2), CPT(3), CPT(4), and the Chemistry Achievement Test (CAT).

In the second section, results relating to the major hypotheses, 1.1, 1.2, 2.1, 2.2, 3.1 are discussed. These results deal with the relationships between proportional reasoning in chemistry and (i) achievement in chemistry, (ii) cognitive functioning level, and (iii) proportional reasoning in nonchemistry contexts, respectively.

The third section of the chapter deals with analysis and discussion of results pertaining to the related questions involving a possible hierarchical sequence of proportional reasoning in both a chemical and nonchemical context and the relationship between sex and cognitive functioning level.

The fourth section of the chapter discusses additional observations concerning proportional reasoning and problem solving in chemistry in view of related findings of the present study. Selected areas which are considered to have more direct implications for the practicing classroom teacher are explored in this final section.

The reader is reminded that the *total study sample* (N = 309) was comprised of: 1) a *main study sample* (N = 168) consisting of students

studying the ALCHEM Chemistry 10 materials, and (ii) a *second study sample* (N = 141) consisting of students enrolled in the CHEM Study version of the Chemistry 10 program. While most of the discussion relates to the main study sample, where indicated, results refer to the total sample (N = 309). A final section dealing with problem solving in introductory chemistry deals with both samples (ALCHEM and CHEM Study) separately.

Item scoring and item analyses for all tests were obtained through facilities of the Testing Division of the Edmonton Public School Board. All statistical calculations were executed on the University of Alberta Amdahl 470 computer, using documented programs of the Division of Educational Research Services (DERS). The level of significance adopted for statistical tests of hypotheses in the study was 0.01. That is, null hypotheses were rejected only if the probabilities of the observed relationships or magnitudes arising by chance were one per cent or less. This decision to accept an alpha level of 0.01 was made with respect to the probabilities of committing Type I (α) and Type II (β) errors in the treatment of the major hypotheses. The probability of rejecting a null hypothesis when it is true (Type I error) is decreased by the choice of a more restrictive level of significance. There also exists, however, the possibility of increasing the probability of a Type II error, i.e., failing to detect a genuine difference when it does occur. For any choice of alpha level and given observed difference, the probability of committing a Type II error is a function of sample size. In the present context, chances of Type II errors occurring are considered sufficiently low in view of the study sample size (N = 168) to warrant the choice of

a higher confidence level of 0.99. This is particularly evident with respect to the classification criteria for the Piagetian Tasks (PT) where every effort was made to give the benefit of any doubt to the student.

The following section presents the results of the test instruments used in the study.

Test Results

The Piagetian Tasks (PT)

The four Piagetian Tasks comprising the PT were described in Chapter III and are presented in booklet form in Appendix B together with the criteria used in assessing student performance on each task.

Student responses to each task were examined in view of the criteria considered indicative of concrete and formal thought. Students meeting the minimum established criteria for each task were considered successful on that task. As such, 'success' refers only to the ability of students to fulfil a set of minimum criteria associated with both concrete and formal operational thought for each of the four tasks. In this sense 'lack of success' on a task infers only that a student failed to adequately fulfil those conditions associated with formal thought. Following assessment of student performance on individual tasks according to the criteria established for each, students in the total study sample (N = 309) were categorized into four broad cognitive levels, concrete operational (C), transitional (T), early formal operational (F1) and late formal operational (F2).

Category (C) included only those students who did not meet the minimum requirements on three or all four of the tasks, the Balance Problem (BP), the Ratio Task (RT), the Metric Puzzle (MP), and the

Islands Puzzle (IP). No distinction was made between the early and late substages of concrete operational thought. Students failing to satisfy minimum requirements on any two of the four tasks presented were said to be operating at a transitional (T) level for purposes of the study. Students meeting criteria on three of the four tasks or all four tasks were said to be operating at the early formal (F1) and late formal operational (F2) levels, respectively. Student performance on each task, together with each student's cognitive level categorization, are presented in Appendix E.

The classification of the total study sample in terms of cognitive functioning level is presented in Table II.

In gross terms, 151 of the total sample of 309 students (48.9%) were found to be capable of using formal operations in their thinking with respect to these tasks and 89 students (28.8%) were still limited to concrete operations. The remaining 69 students (22.3%) were deemed to be at an intermediate or transitional level of thought. This suggestion relies heavily on the assumption that the group administered tasks as used in the study give a valid indication of the levels of cognitive functioning (Rowell and Hoffman, 1975). These general results are in basic agreement with other investigations conducted in the area (Renner and Lawson, 1973; Hobbs, 1975; Field and Cropley, 1968) which indicate that a considerable proportion of high school students are not functioning at the formal operational level.

The decision to categorize the total study sample on the basis of composite task performance rather than single task performance resulted in the omission of any more sensitive analysis. That is, for example a

TABLE II

Total Sample Categorization According to Cognitive Level

N = 309

Cognitive Level	Total Study Sample (N=309)	Main Study Sample (N=168)
Concrete Operational (C)	89 (28.8%)	55 (32.7%)
Transitional (T)	69 (22.3%)	39 (23.1%)
Early Formal (F1)	84 (27.2%)	37 (22.1%)
Late Formal (F2)	67 (21.7%)	37 (22.1%)
TOTAL	309 (100.0%)	168 (100.0%)

student termed transitional (T) refers to his or her overall performance on the set of tasks, rather than to performance on any given task. However, an analysis of the overall task performance revealed that only 44.9 per cent or 139 students of the total sample (N = 309) met the minimum formal operational criteria established for the Islands Puzzle (IP), while 66.0 per cent (204 students) were able to meet the formal criteria on both the Balance Problem (BP) and the Ratio Task (RT). One hundred and sixty-two students (52.4%) met conditions established for the Metric Puzzle (MP).

Table III presents the phi correlation coefficients among the four PT tasks. Intercorrelations based on the phi coefficient were considered to be more appropriate than the Pearson product-moment correlation coefficient as the underlying variable of success or failure on each task as determined in the study was considered to be a dichotomy of a more general underlying cognitive ability variable. That is, students above a certain threshold level on the cognitive variable could meet formal requirements on the PT task, those below could not.

As expected, all four formal operational tasks were found to be significantly intercorrelated ($p < 0.01$). This is understandable in that three of the tasks (BP, RT and MP) dealt directly with the proportionality schema (or at least the understanding of the equivalency between stated ratios) while the fourth, the Islands Puzzle (IP) required the generation of all possible combinations of a hypothetical situation given certain parameters. As such, it possibly taps another subset of formal abilities. For purposes of the present investigation, performance on all four tasks served as a general measure of formal operational thought.

In an effort to gain further insight into the nature of the

TABLE III

Phi Correlation Coefficients for Piagetian Tasks (PT), Balance Problem (BP), Ratio Task (RT), Metric Puzzle (MP) and Islands Puzzle (IP).

N = 309

	BP	RT	MP	IP
BP	1.00			
RT	.42	1.00		
MP	.30	.32	1.00	
IP	.34	.22	.23	1.00

strategies employed by students in answering the Piagetian tasks, a further categorization based on the total sample was attempted using the Ratio Task (RT) as the criterion variable based on the system of categorization described by Wollman and Karplus (1974) referred to in Chapter II. Students' explanations were classified according to the following categories:

Category N (No explanation) - 6 students.

No explanation or statement offered.

Category I (Intuitive) - 2 students.

An explanation referring to estimates, guesses, appearance, or extraneous factors without reference to the data. Examples of predictions or guesses included:

> "I have seen a large flask and it is just larger around the middle. But the height is about the same as the small flask. So I just took a little guess."
>
> "I just guessed."

Category IC (Intuitive Computation) - 13 students.

Here the explanation offered was based on the illogical or haphazard use of the data. Examples included:

> "The small flask's height was four paper clips and weighed 4 paper clips, So if the small flask was 6 paper clips high it should weigh 6 paper clips."
>
> "I found an object that was very close to the size of the large (drawn) paper clip. Then I decided to measure the flask." (answer 3.5).

Category A (Addition) - 72 students.

An explanation focusing on a single difference uncoordinated with other differences, and solving the problem by addition. Examples included:

> "In the small paper clips it took 6 to get 4 large paper clips so you add 2 small paper clips to the height of the large flask." (answer 8).

> "The diagram was 2 clips more than they said it was in the upper part (referring to the written section) so it should be 2 clips higher also." (answer 8).

Category S (Scaling) - 9 students.

An explanation based on a particular ratio that the student does not explain or justify. Examples included:

> "$\frac{6}{4} = \frac{4}{8}$, $4x = 48$
> $x = 12$"

> "The large paper clips are 2/3 as small so all you do is multiply by 2." (answer 10).

Category P (Proportionality) - 207 students.

An explanation using proportional reasoning and relating the scale factor to the data. Examples included:

> "I said 4 is to 6 as 6 is to x. I used proportions to say that $\frac{4}{6} = \frac{6}{x}$, $x = 9$."

> "I saw that the big paper clips were 11/2 times the size of the small paper clips. So I times 1-1/2 the amount I measured the small flask, $1.5 \times 6 = 9$."

Table IV presents the categorization results on the Ratio Task (RT) by per cent. Categories IP (Incomplete Proportion), AS (Addition and Scaling), and the three subcategories of Category P (Proportion), namely Subcategory PC (Proportion, Concrete), Subcategory AP (Additional and Proportion) and Subcategory R (Application of Ratio) used by Wollman and Karplus (1974) in their investigation involving 450 students in Grades seven and eight are not reflected in the present categorization. This is due to both the grade level of the present study (Grade 10) and the manner in which criteria for categorization were established for the set

TABLE IV

Total Sample Categorization on Ratio Task

N = 309

Category	Description	Number	Per Cent
N	No explanation	6	1.9
I	Intuition	2	0.7
IC	Intuitive Computation	13	4.2
A	Addition	72	23.3
S	Scaling	9	2.9
P	Proportionality	207	67.0
	TOTAL =	309	100.0%

of tasks rather than on the basis of individual tasks, discussed earlier. The narrower range of cognitive ability in the present study prevented any finer classification with the overall proportion category (P).

As expected, the majority of students (67.0%) were able to apply proportional reasoning on the Ratio Task (RT). However, the percentage using an additive approach was unexpectedly high (23.3%). Wollman and Karplus (1974) in their investigation of the same task (Ratio Task, Form B) placed approximately one-third of students tested (450, Grades 7 and 8 students) in Category A. Given the Grade 10 level of the total sample, results of the present study reflect an understandable decrease in students responding in Category A. Still, the number of students categorized as additive thinkers remains considerable and appears to represent a persistent mode of reasoning which some students apply in a consistent fashion. Students using additive reasoning tend to treat given data in a simple, well-defined manner directing their attention toward differences in the given information rather than into actual data ratios. For example, in the Ratio Task (RT) the focus is on height difference instead of the height ratio. The high degree of preference placed on the additive mode of reasoning raises a number of questions concerning its application to other situations. Is it, for example, a function of the given ratios themselves? That is, are problems involving simple ratios like 2:1, 2:3, etc., more susceptible to additive approaches than more complex ratios? Is the additive mode of reasoning related to cognitive level? If so, does the additive approach represent a means for the concrete thinker to achieve success on tasks normally requiring formal thought? It may be for example that additive reasoning is an effective concrete strategy, however unsophisticated, enabling a student

to arrive at the correct response with a minimum of abstraction in a sufficient number of situations to warrant its use. In any case, however, additive reasoning will go unnoticed unless the science teacher utilizes more open-ended type questions which reveal student strategies, rather than the more common multiple-choice variety.

Present findings also suggest that this preference for the additive mode prevails even in instances which are suggestive of multiplicative methods. For example in response to the following question on the Balance Problem (BP), Question c (BP):

> Illustrate how you would balance a 20 gram weight placed in the #7 hole of the left hand side of the balance by using a 10 gram weight,

rather than say multiply the weight (20 g) by the distance given (7 holes) and then divide by the new weight (10 g) to yield the required distance, responses given by the additive thinkers did not reflect any step involving multiplication. Additive solutions included subtracting 7 from 20 to yield a new distance of 13 holes or even the addition of 7 to 20 to produce 27 holes!

In any case additive reasoning was clearly evident on both the Balance Problem (BP) and the Metric Puzzle (MP).

For example, on the MP, 16 students or 8.6 per cent were classified as additive in their approach to the problem. Eleven of these 16 students were classified as concrete thinkers (C) on the basis of their performance on all four tasks, while the remaining 5 were classified as transitional (T). Typical explanations for responses from these students included:

> "If you subtract 288-180 you will get 108 difference so I just added 108 to 350."

> "I minused the miles from the kilometers and got 108. Then I added 108 to 350 to get 458."

> "Since the number is 108 higher from miles to kilometers in Calgary it should be the same for Saskatoon."

Preliminary analysis of the nature and extent of student responses suggests that the additive mode does represent a widespread, stable concrete strategy which is clearly not randomly applied.

This section has dealt with the results and categorization of students based on their performance on Piagetian tasks involving proportional reasoning. We turn now to a consideration of students' performance on tests measuring general proportional reasoning.

The General Proportionality Test (GPT) - Form A and Form B

The two forms of the General Proportionality Test, GPT (Form A) and GPT (Form B) are described in Chapter III. Results of the two versions of the GPT are presented in Table V.

The statistical equivalence of the two logical forms of the GPT, discussed earlier, was established on the basis of a preliminary investigation. GPT (Form A) and GPT (Form B) are identical in format with each form containing an initial 15-item multiple-choice section comprised of conversion, ratio, direct and indirect proportionality questions, followed by a 5-item verbal reasoning section and a 10-item verbal analogy section. The final section consists of four numerical series questions in which students are required to specify reasons for their chosen responses. Item analyses, excluding the open-ended numerical series section for both forms of the GPT, are presented in Appendix F. The four proportionality types (i.e. conversion, ratio, direct proportionality and indirect proportionality) corresponding to each GPT item are also indicated in

TABLE V

Pearson Product-Moment Intercorrelations, Means and Standard Deviations for Test Scores on the Piagetian Tasks (PT), General Proportionality Tests - GPT(A) and GPT(B), Chemistry Proportionality Tests - CPT(1) Nomenclature and Formulae Writing; CPT(2) Chemical Reactions; CPT(3) The Mole; CPT(4) Gravimetric Stoichiometry, and the Chemistry Achievement Test (CAT)

N = 168

	(PT)	GPT(A)	GPT(B)	CPT(1)	CPT(2)	CPT(3)	CPT(4)	CPT(T)	CAT
PT	1.00								
GPT(A)	.48	1.00							
GPT(B)	.36	.52	1.00						
CPT(1)	.45	.38	.33	1.00					
CPT(2)	.55	.46	.44	.67	1.00				
CPT(3)	.54	.50	.40	.55	.65	1.00			
CPT(4)	.42	.37	.29	.57	.64	.58	1.00		
CPT(T)	.58	.50	.44	.83	.86	.83	.82	1.00	
CAT	.48	.46	.41	.65	.70	.66	.67	.79	1.00
Mean	2.3	23.9	22.1	16.3	12.8	13.3	9.2	51.6	36.7
Standard Deviation	1.1	4.0	4.2	4.1	3.0	3.8	3.1	12.1	9.9

Appendix F.

The Kuder-Richardson reliability coefficients (KR-20) for the internal consistency of GPT (Form A) and GPT (Form B) of 0.68 and 0.74, respectively, were considered acceptable in view of the nature of the instruments. That is, the four separate sections within each GPT form tend to increase the heterogeneity of the tests.

The average test scores for GPT(A) and GPT(B) expressed as percentages are equal to 70.3 per cent and 65.0 per cent, respectively. In terms of difficulty it appears that the students found the tests relatively easy. For both the main study sample (N = 168) and the CHEM Study sample (N = 141), no significant differences were noted between means on the pretest and posttest forms. The main study sample received GPT(A) as a pretest and GPT(B) as a posttest while the reverse was true for the CHEM Study sample.

The Pearson product-moment correlation coefficient between GPT(A) and GPT(B) (r = 0.52), together with the above non-significant mean differences on the pretest and posttest scores, are discussed in the second section of this chapter dealing with the relationship between proportional reasoning in chemistry and proportional reasoning in a nonchemistry context. The section which follows addresses itself to results of the test instruments used to assess student performance in selected areas of introductory chemistry involving proportional reasoning.

The Chemistry Proportionality Test (CPT)

The Chemistry Proportionality Test (CPT), described in Chapter III, consists of four subtests, in two sections, dealing with the

following topics in introductory high school chemistry: CPT(1) - Nomenclature and the Writing of Formulae; CPT(2) - Chemical Reactions; CPT(3) - The Mole, and CPT(4) - Gravimetric Stoichiometry. Means, standard deviations and Pearson product-moment intercorrelations of the multiple choice portions of the CPT subtests are included in Table V. Item analyses for items in each subtest are presented in Appendix F.

The CPT subtest means expressed as percentages are equivalent to 65.2, 64.0, 66.5, and 61.3 per cent, respectively. The mean for the total Chemistry Proportionality Test, CPT(T), is equivalent to 64.5 per cent. These findings are consistent with results of the initial forms of the CPT subtests administered in the preliminary studies and are in general agreement with the consensus of the seven chemistry teachers involved in the main study who felt that the CPT subtests were fairly difficult but content valid tests of material pertaining to proportionality in the Chem 10 ALCHEM Materials.

The calculated KR-20 internal consistency coefficients for the CPT subtests of 0.70, 0.61, 0.77, and 0.70 are in substantial agreement with KR-20 values of 0.69 and 0.74 calculated for GPT(A) and GPT(B), respectively. The CPT subtest items were constructed so as to illustrate chemistry aspects of the proportionality schema analogous to those found in the General Proportionality Test (GPT). As such one would expect similar KR-20's for these test instruments as noted. Specific items corresponding to the proportionality types are indicated in Appendix F. The inclusion of conversion type, ratio type and direct proportionality type problems in each subtest may have suppressed KR-20 values by decreasing the homogeneity of the subtests.

All intercorrelations presented in Table V among the CPT subtests, the CPT(T) and Chemistry Achievement Test (CAT) scores are significant ($p < 0.01$). The high correlation noted between CPT(T) and CAT ($r = 0.79$, $p < 0.001$) is discussed in the second section of the chapter dealing with the relationship between proportional reasoning in chemistry and achievement in chemistry.

The Chemistry Achievement Test (CAT)

The Chemistry Achievement Test (CAT) was made available to the investigator by the Director of Pupil Assessment Branch of the Edmonton Public School Board. The 60 multiple-choice items on the CAT were developed to assess specific content objectives of the Chemistry 10 course. Cluster topics and question numbers on the CAT are as follows:

Cluster	*Unit*	*Topic*	*Questions*
1	A	Elements and the Periodic Table	1 - 8
2	B	Compounds and Nomenclature	44 - 49, 56 - 60
3	C (first part)	Chemical Reactions	9 - 16
4	C (second part)	Chemical Reactions	50 - 55
5	D	The Mole	17, 19 - 24, 31 - 37
6	E	Gravimetric Stoichiometry	18, 25 - 30, 38 - 43.

In the present investigation the CAT serves as a general measure of achievement in introductory chemistry. Results for the CAT are presented in Table V. For the students in the present study, the average score of 36.7 on the CAT is equal to 61.2 per cent with a standard deviation of 9.9. An internal consistency coefficient (KR-20) of 0.87 was calculated for the study sample, which compares favorably with the reported CAT KR-20

coefficient of 0.88 (EPSB Chemistry 10 Survey Test Manual, 1974). Test statistics for the CAT are presented in Appendix F.

The frequency distribution of the CAT scores given in Figure 1 shows a rather wide range of scores, with the highest frequency of scores occurring near the mean. In order to investigate how students' performance on the various proportionality measures is related to different levels of achievement, the main study sample was divided into three nearly equal groups on the basis of their CAT achievement scores. This was done by using the frequency distribution of the CAT to establish, as nearly as possible, three groups of equal size (high, middle, low). Cutting points at 31 and 42 produced three nearly equal groups of 57, 54 and 57 students, respectively.

Table VI shows the distribution of male and female students in the main study sample within the three achievement groups. The sample was 53.6 per cent male and 46.4 per cent female. A chi-square test of independence performed on the test data indicated that there is no significant difference in performance on the CAT for the three groups according to sex.

This initial section has presented the results of the instruments used in the study. The following section presents the results and discussion associated with the relationships among the study variables. Statistical procedures associated with the treatment of particular hypotheses are discussed in conjunction with the results.

Major Hypotheses and Data Analysis Procedures

The major hypotheses are discussed under three main headings: i) proportional reasoning and chemistry achievement, ii) proportional

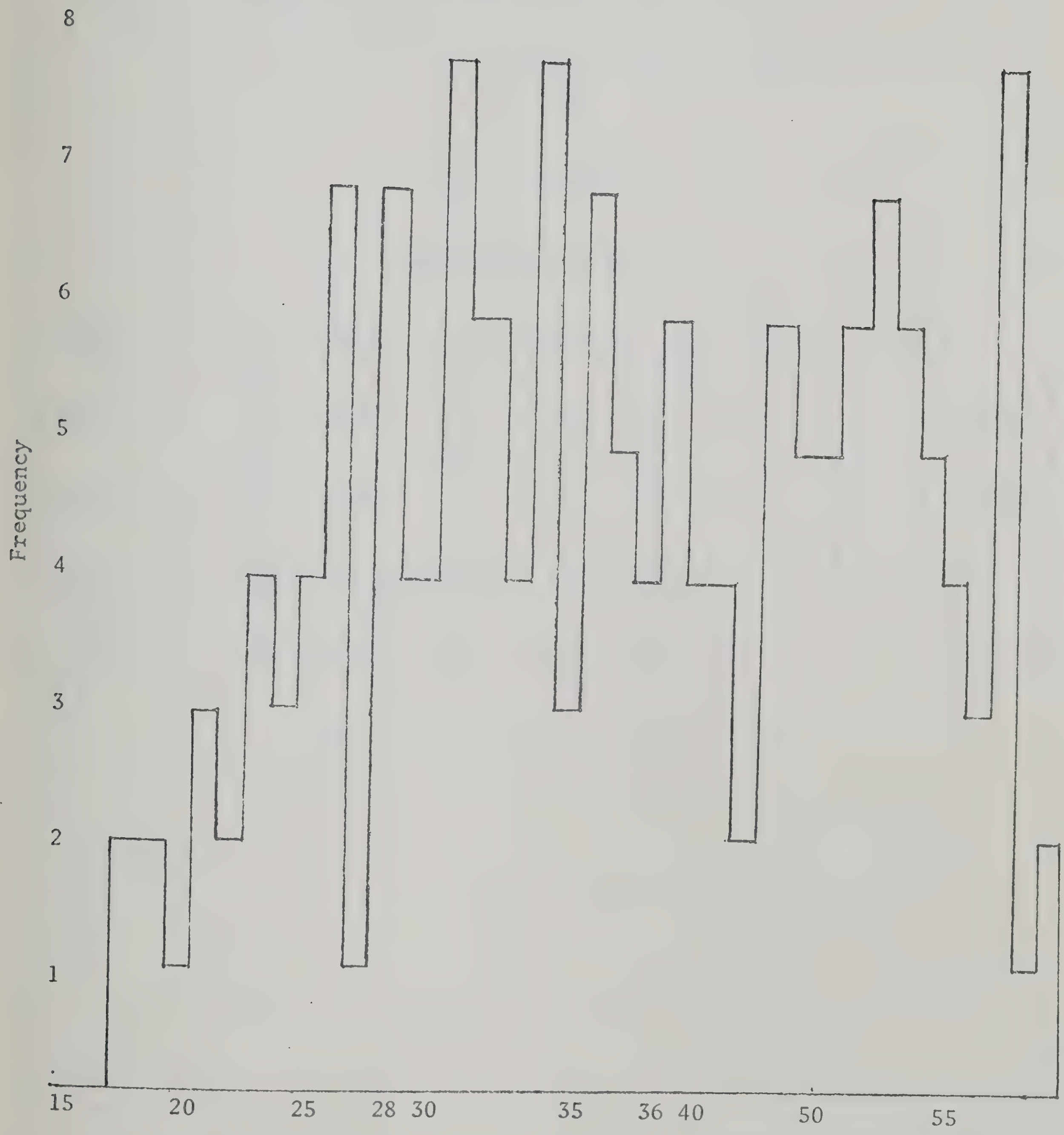


Fig. 1. Frequency distribution of the CAT scores, Mean = 36.7, N = 168.

TABLE VI

Distribution of Main Study Sample by Sex in

High, Middle and Low Achievement Groups.

N = 168

Achievement Group

Sex	High	Middle	Low	Total
Male	35	27	28	90 (53.6%)
Female	22	27	29	78 (46.4%)
Total	57	54	57	168 (100.0%)

($\chi^2 = 2.0$, df = 2, $.30 < p < .50$)

reasoning and cognitive level, and iii) proportional reasoning in chemistry and nonchemistry contexts.

i) *Proportional Reasoning and Chemistry Achievement*

In this initial section the relationships between proportional reasoning in chemistry and chemistry achievement (Hypothesis 1.1) and proportional reasoning in general and chemistry achievement (Hypothesis 1.2) are discussed in turn.

Hypothesis 1.1 - Proportional Reasoning in Chemistry and Chemistry Achievement

Hypothesis 1.1 states that there is no significant relationship between student ability to apply proportional reasoning in chemistry as measured by the CPT, and achievement in chemistry, as measured by the CAT. Intercorrelations of the CAT with the four subtests of the CPT and the total performance score on the Chemistry Proportionality Test, CPT(T), are presented in Table V. All correlation coefficients exceed the critical value of 0.25 (df = 98) at the $p = 0.01$ level of significance.

Of the four CPT subtests, CPT(2) 'Chemical Reactions', has the highest correlation with the CAT scores ($r = 0.70$, $p < .001$). To determine the extent to which performance on the CPT subtests contributed to the variance of the chemistry achievement scores, a stepwise regression analysis was carried out on the prediction of the CAT score using the two forms of the General Proportionality Test, GPT(A) and GPT(B), the set of four Piagetian Tasks, PT, the four CPT subtests and the total Chemistry Proportionality Test, CPT(T) scores as predictor variables.

The stepwise regression procedure makes use of the matrix of intercorrelations among the variables and enters into regression the variable

most highly correlated with the variable being predicted, in this case the CAT score. The next step involves selecting and entering into regression that predictor variable, from the remaining predictors, which has the highest partial correlation with the CAT score. This stepwise process continues with the re-examination at every stage of the regression of the partial correlations of the remaining predictor variables with the criterion variable, until all specified predictors have been entered into the model (Draper and Smith, 1966, p. 171-173).

Results of the stepwise regression analysis for the prediction of achievement in chemistry from eight major study variables are presented in Table VII. The only significant variable entering the regression equation is the total Chemistry Proportionality Test score, CPT(T), which accounts for 61.7 per cent of the variance in the CAT scores. It may be noted that no other major test or subtest significantly enters the regression equation over and above the contribution of the total score, CPT(T).

In an effort to determine the predictive value of the individual CPT subtests on the CAT achievement scores, a further stepwise regression analysis using 13 predictor variables was performed. In addition to the four CPT subtest scores taken separately, the four sections of the General Proportionality Test, GPT(A), the four Piagetian tasks, the Balance Problem (BP), the Ratio Task (RT), the Metric Puzzle (MP) and the Islands Puzzle (IP) and the total score on these tasks (PT) served as predictors. Table VIII presents the results of this regression analysis. The first variable entering the regression equation is the CPT(2) subtest score, 'Chemical Reactions', which accounts for 48.9 per

TABLE VII

Prediction of Chemistry Achievement (CAT) Scores from the General Proportionality Tests, GPT(A) and GPT(B), the Chemistry Proportionality Subtests, CPT(1), CPT(2), CPT(3), CPT(4) and Total Score CPT(T)

Predictor Variable Entering	F Value for Variable Entering	Total F Value	Probability Level	R^2 (per cent)
CPT(T) Chemistry Proportionality Test - Total Score	268.0	268.0	$< .001$	61.7

Regression equation in raw-score form is given by:

$$\hat{Y}_{CAT} = 0.65 X_{CPT(T)} + 3.2$$

TABLE VIII

Prediction of Chemistry Achievement (CAT) Scores from Sections of the General Proportionality Test, GPT(A), the Balance Problem (BP), the Ratio Task (RT), the Metric Puzzle (MP), the Islands Puzzle (IP), the Total Score on the Piagetian Tasks (PT), and the Chemistry Proportionality Subtests, CPT(1), CPT(2), CPT(3), CPT(4).

Prediction Variable Entering	F Value for Variable Entering	Total F Value	Probability Level	R^2 (per cent)
CPT(2)-'Chemical Reactions'	159.2	159.2	.001	48.9
CPT(4)-Gravimetric Stoichiometry	31.3	109.8	.001	57.1
CPT(3)-'The Mole'	16.6	85.7	.001	61.0
CPT(1)-'Nomenclature and the writing of formulae	10.6	70.7	.0014	63.4

Regression equation in raw-score form is given by:

$$\hat{Y}_{CAT} = 0.80\ X_{CPT(2)} + 0.63\ X_{CPT(4)} + 0.75\ X_{CPT(3)} + 0.53\ X_{CPT(1)} + 2.7$$

cent of the variance in the CAT scores. The second subtest to enter the equation significantly is the CPT(4), 'Gravimetric Stoichiometry', which increases R^2 to 57.1 per cent. CPT(3), 'The Mole', and CPT(1), 'Nomenclature and the Writing of Formulae', were entered next, increasing the total variance accounted for by the four CPT subtests to 63.4 per cent. Consistent with the previous analysis, no other predictor significantly entered the regression equation. Results of the stepwise regression analysis are in agreement with the correlational data. That is, CPT(2), 'Chemical Reactions', the most significant predictor of chemistry achievement, had the highest correlation coefficient with CAT ($r = 0.70$) while CPT(1), 'Nomenclature and the Writing of Formulae', the last significant predictor to enter the regression equation, had the lowest ($r = 0.65$).

Results of a principal-factor solution (Harman, 1970, p. 135-143) performed on the matrix of intercorrelations of eighteen variables (i.e. the sections of GPT(A) and GPT(B), the Piagetian tasks, BP, RT, MP, IP and total performance, PT, and the proportionality subtests, CPT(1), CPT(2), CPT(3), CPT(4)), are presented in Table IX.

The 'method of principal factors' is an application of the method of principal components to the reduced correlation matrix (i.e. with communalities in place of the ones in the principal diagonal) (Harman, 1970, p. 137). The method used in the present study used squared multiple correlations (S.M.C.'s) as the 'best possible' estimates of the communalities (Guttman, 1956). The calculated S.M.C.'s as communality estimates are included together with the observed communalities in Table IX.

TABLE IX

Principal - Factor Solution

Varimax Rotation

	Tests	Factors			Communalities	
		1.	2.	3.	Original	Estimated
1.	General Proportions - GPT(A)	.41	.36	.38	.43	.45
2.	Verbal Reasoning - GPT(A)	.21	.08	.44	.25	.31
3.	Verbal Analogy - GPT(A)	.01	.17	.50	.27	.27
4.	Numerical Series - GPT(A)	.17	.16	.18	.09	.19
5.	Balance Problem - BP	.12	.57	.02	.34	.51
6.	Ratio Rask-RT	.29	.54	.15	.38	.54
7.	Metric Puzzle - MP	.36	.58	.08	.47	.67
8.	Islands Puzzle - IP	.20	.49	.30	.37	.63
9.	Piagetian Tasks - PT	.28	.92	.19	.96	.88
10.	Chemistry Proportionality-CPT(1)	.69	.25	.17	.56	.55
11.	Chemistry Proportionality-CPT(2)	.74	.34	.23	.72	.68
12.	Chemistry Proportionality-CPT(3)	.63	.36	.30	.61	.60
13.	Chemistry Proportionality-CPT(4)	.72	.19	.18	.58	.55
14.	General Proportions - GPT(B)	.25	.24	.48	.35	.37
15.	Verbal Reasoning - GPT(B)	.12	.03	.53	.30	.29
16.	Verbal Analogy - GPT(B)	.12	.02	.46	.23	.24
17.	Numerical Series - GPT(B)	.14	.20	.21	.10	.19
18.	Chemistry Achievement - CAT	.78	.24	.24	.72	.67
	VARIANCE	3.21	2.73	1.80		
	% TOTAL VARIANCE	17.83	15.14	9.96		
	% COMMON VARIANCE	41.53	35.38	23.20		
	SUM OF COMMUNALITIES			7.73		
	TOTAL VARIANCE ACCOUNTED FOR =			43.92		

Under normal varimax rotation, the solution revealed three factors, two with eigenvalues greater than unity and the third with a value of .82. The first factor, accounting for 17.8 per cent of the total variance, appears to reflect a general ability involving to a considerable extent the proportionality schema. All four Chemistry Proportionality Subtests, CPT(1), CPT(2), CPT(3) and CPT(4), together with the achievement measure (CAT) loaded heavily on this first factor. The possible existence of a general factor associated with both the CPT and the CAT, as was suggested by regression analysis, provides further support for the significant relationship existing between these two criterion measures.

The four Piagetian tasks, BP, RT, MP, IP, and the total performance score on these tasks, PT, loaded most heavily on the second factor. Results of the principal-factor solution are in substantial agreement with those of Bart (1971) on the factor structure of formal operations. Bart administered four formal Piagetian tasks and three formal operational reasoning tests dealing with the content areas of biology, history and literature. The total sample (N = 90) was comprised of 30 scholastically above average adolescents at each of three age levels, 13, 16 and 19. Maximum likelihood factor analysis showed all four tasks and the three reasoning tests loaded heavily (accounting for 58.8 per cent of the common variance) on a general factor with the three reasoning tests loading heavily on the secondary factor. This secondary factor was said to distinguish the formal tasks from the formal reasoning tests. Although the content areas differ from that of the present study, results of the present study in

introductory high school chemistry also revealed a second factor which served to distinguish the tasks (i.e. BP, RT, MP and IP) from the tests (i.e. the Chemistry Proportionality Subtests, CPT(1), CPT(2), CPT(3), CPT(4)). A third somewhat unclear factor identified in Table IX appears to be associated with sections of the General Proportionality Test (GPT), especially those items dealing with verbal reasoning and verbal analogy. That is, these particular sections on both the pretest form (GPT(A)), and posttest form (CPT(B)), loaded rather heavily on this third factor. The two loading clusters of nearly equal magnitude associated with the GPT pretest and posttest forms may also be interpreted as a further indication of the statistical equivalency of these test instruments. Further, the consistent nature of the factor loadings for the 'General Proportions' and 'Verbal Analogy' sections on both forms is in agreement with findings of Lovell and Butterworth (1966), which indicated that verbal analogy type items loaded heavily on tasks involving the proportionality schema (e.g. .84). The non-significant factor loadings noted for the 'Numerical Series' section on both GPT forms indicates that performance on items of this nature is not represented by a dimension reflected in the domain of the third factor. It may be that students' ability on tasks involving completion of numerical series, e.g. Item 33 - GPT(A):

> The next number in the series is:
>
> 4, 10, 28, 82, ☐,

is independent of those tasks involving the proportionality schema more directly, for example Item 34 - GPT(A):

Determine the missing number.

3	6	7	10
12	24	28	☐

.

There was a considerable range of difficulty levels associated with the four item types included in the numerical series section of the GPT forms. In general the completion of series items were found to be much easier than the proportionality types.

Means and standard deviations for the nine main test instruments for each of the three achievement groups (high, middle, low) are presented in Table X. Based on the 1 to 4 scoring system used for the Piagetian Tasks, the mean of 3.0 for the high group on PT indicates that most students in this group are capable of formal operational thought. The means for the middle and low achievement groups or those on PT indicate that the majority of students in these groups are operating at a transitional or late concrete level of thinking, respectively.

In a similar manner, means for the high, middle and low achievement groups on both the CPT(T) and CAT scores serve to discriminate among the three groups. For example the mean for the high group on the CAT, expressed as a percentage, is 80 per cent compared to only 42.5 per cent for the low achievement group. However, means for the three achievement groups for both forms of the General Proportionality Test do not reflect such an acute distinction. This lack of discriminating

TABLE X

Test Score Means and Standard Deviations for Nine Main Study Instruments for the Three Achievement Groups (High, Middle, Low)

N = 168

Test	High Mean (S.D.)	Middle Mean (S.D.)	Low Mean (S.D.)
1. General Proportionality Test GPT(A)	26.5 (2.7)	23.2 (4.4)	22.2 (3.5)
2. General Proportionality Test GPT(B)	24.4 (4.5)	21.6 (4.9)	20.1 (3.6)
3. Piagetian Tasks (PT)	3.0 (1.1)	2.2 (1.0)	1.7 (0.9)
4. Nomenclature and the Writing of Formulae CPT(1)	19.4 (3.1)	16.2 (3.2)	13.2 (3.4)
5. Chemical Reactions CPT(2)	15.2 (2.4)	12.6 (1.9)	10.3 (2.4)
6. The Mole CPT(3)	16.7 (2.4)	12.6 (3.1)	10.6 (2.9)
7. Gravimetric Stoichiometry CPT(4)	11.7 (2.2)	9.1 (2.5)	6.8 (2.6)
8. Chemistry Proportionality Test CPT(T)	63.2 (7.6)	50.6 (7.3)	40.9 (8.5)
9. Chemistry Achievement Test CAT	48.0 (3.6)	36.6 (3.2	25.5 (4.0)

ability noted for the GPT forms between achievement groups (e.g. high, middle and low group means for GPT(A) were 26.5, 23.2 and 22.2, respectively) may be related to the relatively easy nature of the instruments mentioned earlier (overall means for GPT(A) and GPT(B) were 70.3 and 65.0 per cent, respectively). It could also mean that students have mastered the operations tested in the *contexts presented.* However, the failure of the GPT forms to discriminate between achievement groups is also reflected in the standard deviation values for the three groups. The greater variance associated with the middle achievement group for both GPT forms suggests a rather flattened distribution across the three groups. Although standard deviations are fairly similar for other tests across achievement groups, they are indicative of more "bell shaped" distributions.

Table XI presents the results of the one-way analysis of variance for the high, middle and low achievement groups for eight test scores. Means on all eight test instruments are significantly different ($p < 0.001$) for the three groups.

Table XII presents the Sheffé probability matrices for the multiple comparison of the eight test means for the three achievement groups. As expected from the previous discussion regarding the low discriminatory power of the General Proportionality Test forms, GPT(A) and GPT(B), non-significant mean differences are reflected in the Sheffé probability matrices for these test forms. Both mean differences for the high and middle achievement groups for GPT(A) and GPT(B) are non-significant ($p = 0.37$ and 0.20, respectively). However, mean differences for the high and low achievement groups on the GPT forms

TABLE XI
One Way Analysis of Variance
on Eight Test Scores for High,
Middle, and Low Achievement Groups
N = 168

Test	Source	Df	SS	MS	F	p
1. General Proportionality Test - GPT(A)	groups error	2 165	567.1 2172.5	283.5 13.2	21.5	< 0.001
2. Piagetian Tasks PT	"	"	48.4 181.5	24.2 1.1	21.9	< 0.001
3. Nomenclature and Formulae Writing CPT(1)	"	"	1081.6 1796.1	540.8 10.9	49.7	< 0.001
4. Chemical Reactions CPT(2)	"	"	683.6 866.3	341.8 5.3	65.1	< 0.001
5. The Mole CPT(3)	"	"	1091.0 1334.9	545.5 8.1	67.4	< 0.001
6. Gravimetric Stoichiometry CPT(4)	"	"	675.7 1000.8	337.8 6.1	55.7	< 0.001
7. Chemistry Proportionality Test - CPT(T)	"	"	14208.9 10201.6	7104.5 61.8	114.9	< 0.001
8. General Proportionality Test - GPT(B)	"	"	533.0 3129.8	266.5 18.9	14.0	< 0.001

TABLE XII

Sheffé Probability Matrices for Eight Test Variables for High, Middle, and Low Achievement Groups

N = 168

Test		Probability Matrix High	Middle	Low
1. General Proportionality Test - GPT(A)	High			
	Middle	0.37		
	Low	<0.001	<0.001	
2. Piagetian Tasks - (PT)	High			
	Middle	0.10		
	Low	<0.001	0.001	
3. Nomenclature and Formulae Writing - CPT(1)	High			
	Middle	<0.001		
	Low	<0.001	<0.001	
4. Chemical Reactions - CPT(2)	High			
	Middle	<0.001		
	Low	<0.001	<0.001	
5. The Mole - CPT(3)	High			
	Middle	<0.001		
	Low	<0.001	<0.001	
6. Gravimetric Stoichiometry - CPT(4)	High			
	Middle	<0.001		
	Low	<0.001	<0.001	
7. Chemistry Proportionality Test - CPT(T)	High			
	Middle	<0.001		
	Low	<0.001	<0.001	
8. General Proportionality Test - GPT(B)	High			
	Middle	0.20		
	Low	<0.001	<0.001	

are significant ($p < .001$). A non-significant difference was noted between the middle and high achievement group on the set of Piagetian Tasks (PT). This finding might well be expected in view of the difficulty in attempting to distinguish between those students operating at a transitional level of thought (i.e. predominately middle achievers) and those at the early or late formal level (i.e. high achievers).

On the basis of results presented, hypothesis 1.1 is rejected. There appears to be a significant relationship between students' ability to apply proportional reasoning in chemistry, as measured by the CPT, and student achievement in chemistry, as measured by the CAT.

Hypothesis 1.2 - Proportional Reasoning in General and Chemistry Achievement

Hypothesis 1.2 states that there is no significant relationship between students' abilities to apply general proportional reasoning as measured by the GPT, and achievement in chemistry as measured by the CAT. The Pearson product-moment correlation coefficients between the General Proportionality Test, GPT(A), and the achievement measure, CAT, and the General Proportionality Test, GPT(B) and chemistry achievement, CAT, are presented in Table V. Of the two forms, GPT(A) had the higher correlation with the CAT achievement scores ($r = 0.46$). Both correlation coefficients are significant at the 0.01 level.

As discussed in an earlier section, no significant differences were noted between the means of the pretest and posttest forms (GPT(A) and GPT(B) respectively) for the main study sample. However, the significant correlation ($r = 0.52$, $p < .01$) found to exist between GPT(A) and GPT(B) was remarkably low in view of the previously established statistical equivalence of these two instruments. That is, one might have predicted

more than 25 per cent of common variance shared between GPT(A) and GPT(B). The investigator is unable to offer a suitable explanation for this apparent irregularity at this time. It should be noted, however, that of the two forms, the pretest form, GPT(A), correlates more highly with achievement in chemistry (CAT) ($r = 0.46$, $p < .01$) than the posttest form, GPT(B). It may well be that, rather than having a positive effect on general proportional reasoning ability, the extended exposure to proportional reasoning in chemistry reduces student performance on a test of general proportionality. That is, instead of enhancing the relationship between proportional reasoning in chemistry and general proportional reasoning, the effect is to further dichotomize the two, possibly because the relatively unfamiliar context of chemistry serves to confuse the issue for the student. While this is only conjecture at this point, relationships which may underlie reasoning abilities in various contexts present an area for further research.

In addition to a total score for each GPT form, separate scores were obtained for each of the four types of items on the test: 'General Proportions' - 'Verbal Reasoning', - 'Verbal Analogy' and 'Numerical Series'. Mean differences for these sections for the two GPT forms were noted to be non-significant. That is, 't' values calculated on the intercorrelational matrix for respective sections on each form to test the hypothesis that $r = o$, all proved to be significant ($p < .001$). Table XIII presents the means and standard deviations for the pretest and posttest GPT scores.

Despite their somewhat low intercorrelations the GPT forms are considered to be both logically and statistically equivalent as

TABLE XIII

Means and Standard Deviations for

Pretest and Posttest Measures : GPT(A) and GPT(B)

N = 168

Section	Pretest GPT(A)		Posttest GPT(B)	
	Mean	S.D.	Mean	S.D.
General Proportions (15)	10.8	5.0	9.7	6.4
Verbal Reasoning (5)	4.0	0.9	4.1	1.2
Verbal Analogy (10)	6.8	3.8	5.9	5.6
Numerical Series (4)	2.3	0.6	2.4	0.8
TOTAL (34)	X = 23.9	4.0	X = 22.1	4.2

( ) = number of items per section

determined by the results of preliminary investigations (referred to in Chapter III). Hence the consistency of the pretest and posttest findings reported in Table XIII are particularly noteworthy. Students' exposure to prolonged instruction in chemistry, which draws heavily on all levels of the proportionality schema, appears to have little or no effect on students' ability to apply the schema in a more general or common sense.

On the basis of the significant correlational relationship found to exist between GPT(A), GPT(B) and performance on the CAT (r = 0.46 and 0.41, respectively), hypothesis 1.2 is rejected. While chemistry instruction does not appear to enhance proportional reasoning in a non-chemistry context, there appears to be a significant relationship between students' ability to apply general proportional reasoning and achievement in chemistry.

The following section deals with the hypothesized relationship between proportional reasoning, CPT and GPT, and cognitive level (PT).

ii) *Proportional Reasoning and Cognitive Level*

Hypothesis 2.1 - Proportional Reasoning in Chemistry and Cognitive Level

Hypothesis 2.1 states that there is no significant relationship between student scores on tests involving proportional reasoning in chemistry (CPT) and cognitive functioning level as measured by Piagetian criteria indicative of proportional reasoning (PT). Correlation coefficients for each of the CPT subtests, CPT(1), CPT(2), CPT(3), CPT(4) and the total Chemistry Proportionality Test score, CPT(T) with the Piagetian Tasks (PT) are included in Table V. All coefficients are significant at the 0.01 level.

It was noted earlier that CPT(T) correlated highly with the CAT achievement scores ($r = 0.79$, $p < 0.001$). This relationship was further supported by high loadings on a general factor associated with overall achievement in chemistry and the proportionality subtests. Based on these findings, CPT(T) itself can be considered a measure of achievement in chemistry. On the basis of the significant relationship between CPT(T) and the CAT scores, the main study sample was divided into three equal achievement groups of 56 students each based on the CPT(T) scores and categorized according to cognitive level. The results of this analysis are presented in Table XIV. A highly significant chi square was noted for the relationship between cognitive level and the total Chemistry Proportionality Scores, CPT(T) ($\chi^2 = 59.2$, $df = 6$, $p < 0.001$) with only 7 students (12.5%) in the low group classified as formal thinkers compared to a total of 41 students (73.2%) in the high group. These results are consistent with the sample distribution according to cognitive level based on the CAT achievement scores presented in Table XV ($\chi^2 = 47.7$, $df = 6$, $p < 0.001$).

On the basis of the significant relationship between the Chemistry Proportionality Test (CPT) and performance on the PT, hypothesis 2.1 is rejected. There appears to be a significant relationship between proportional reasoning in chemistry and cognitive level.

Hypothesis 2.2 - Proportional Reasoning in General and Cognitive Level

Hypothesis 2.2 states that there is no significant relationship between student scores on tests involving general proportional reasoning (GPT) and cognitive functioning level as measured by the

TABLE XIV

Distribution of Sample by Cognitive Level and Total Chemistry Proportionality Scores [CPT(T)].

N = 168

Cognitive Level	High	Middle	Low	Total
Concrete (C)	3	21	31	55
Transitional (T)	12	9	18	39
Early Formal (F1)	14	18	5	37
Late Formal (F2)	27	8	2	37
TOTAL	56	56	56	168

$\chi^2 = 59.2$, df = 6, $p < .001$

TABLE XV

Distribution of Sample by Cognitive Level and Achievement Scores (CAT)

N = 168

Cognitive Level	High	Middle	Low	Total
Concrete (C)	6	19	30	55
Transitional (T)	11	12	16	39
Early Formal (F1)	13	18	6	37
Late Formal (F2)	27	5	5	37
TOTAL	57	54	57	168

$\chi^2 = 47.7$, df = 6, $p < .001$

Piagetian tasks (PT). Correlation coefficients between GPT(A) and PT and GPT(B) and PT are presented in Table V. Both coefficients are significant at the 0.01 level. Of the two forms of the GPT, GPT(A) administered as a pretest measure of general proportional reasoning, had the higher correlation with PT ($r = 0.48$). This is similar to the finding, discussed in the previous section, which indicated that the GPT(A) pretest also had the higher correlation with achievement in chemistry ($r = 0.46$, $p < 0.01$) than did the GPT(B) posttest. One explanation offered for the higher correlation with the pretest measure had to do with a possible adverse interaction between proportional reasoning in chemistry (CPT) and general proportional reasoning (GPT). As mentioned earlier this adverse interaction may be a result of the unfamiliarity with the chemistry context which tends to cloud the students' thinking. In any case the decrease in the general proportionality measure scores as a posttest, GPT(B), would also account for the correspondingly lower correlation noted between GPT(B) and PT.

Of the four sections in GPT(A), the first dealing with general proportions correlated most highly ($r = 0.48$) with overall performance on the Piagetian tasks (PT) while the section on 'verbal reasoning' correlated least highly ($r = 0.22$). Within the tasks themselves, the Metric Puzzle (MP) correlated most highly with overall performance on the GPT(A) ($r = 0.47$) while the Islands Puzzle (IP) was noted to have the lowest correlation with general proportional reasoning ($r = 0.31$). The IP also yielded the lowest phi correlation coefficient among the four tasks. This is understandable in that MP involves the proportionality schema directly while IP is associated more with combinatorial

properties of formal thought. IP was included in the set of Piagetian Tasks in order to give a more general measure of formal operational thought.

On the basis of the significant relationship found between GPT and PT, hypothesis 2.2 is rejected. There appears to be a significant relationship between general proportional reasoning and cognitive functioning level.

The following section deals with the relationship between proportional reasoning in a chemical context (CPT) and proportional reasoning in a non-chemical context (GPT).

iii) *Proportional Reasoning in Chemistry and Non-Chemistry Contexts*

Hypothesis 3.1 -

Hypothesis 3.1 states that there is no significant relationship between students' ability to apply proportional reasoning in chemistry (CPT) and application of proportionality in areas not content-specific to chemistry (GPT). Table XIII presents the results of 't' tests performed on the overall means for the pretest, GPT(A), and posttest, GPT(B), measures of general proportional reasoning. No significant difference was noted between the two forms. That is, it appears that students' exposure to chemistry instruction involving proportional reasoning has little or no effect on their ability to apply more general proportional reasoning.

The main study sample (N = 168) was divided into three equal groups of 56 students each based on performance on the GPT(A). Table XVI presents this sample categorized by cognitive level. A highly significant chi square ($\chi^2 = 59.5$, df = 6, $p < .001$) was noted, with only

TABLE XVI

Distribution of Sample by Cognitive Level Based on General Proportionality Test Scores, GPT(A)

N = 168

Cognitive Level	High	Middle	Low	Total
Concrete (C)	4	18	33	55
Transitional (T)	19	18	1.2	39
Early Formal (F1)	15	15	7	37
Late Formal (F2)	28	5	4	37
TOTAL	56	56	56	168

$\chi^2 = 59.5$, df = 6, $p < .001$

eleven formal operational students (6.5 per cent) in the low group compared to forty-three formal students (24.4%) in the high group.

While those students deemed formal in their thinking performed significantly better on both the CPT subtests and the pretest and posttest forms of the GPT, non-significant gains were noted for concrete thinkers on these measures. This is in agreement with the work of Herron (1975) who found a substantial correlation ($r = 0.70$) between performance on a battery of Piagetian tasks and scores on a chemistry placement test at the freshman college level. On the basis of results presented, hypothesis 3.1 is rejected. While instruction in proportional reasoning in chemistry CPT does not appear to enhance general proportional reasoning GPT there appears to be a significant relationship between students' ability to apply proportional reasoning in a chemical context and ability to apply proportionality in areas not content-specific to introductory chemistry.

The following section deals with two major questions related to the present investigation. This section is followed by a general discussion of the overall findings of the study.

Related Questions

Question 1. Proportionality Hierarchy

This first question attempts to determine whether those tasks used in the present study to measure proportional reasoning represent a hierarchy of capabilities. As used in the present study hierarchy refers only to the postulated sequence of proportionality components (i.e. conversion - ratio - direct proportionality - indirect proportionality) identified in the study. The derivation of a learning hierarchy or a

Gagné task analysis in the pure sense is not applicable to the present investigation. In order to validate a given learning hierarchy, based on Gagné's model, data on each individual rather than group data would have to be obtained. The present preliminary hierarchical analysis considers only the item difficulties based on the main sample (N = 168) performance on item clusters associated with respective types of proportionality. While it is noted that an item difficulty approach is insufficient for establishing a learning hierarchy it does represent an underlying prerequisite condition for a hierarchy.

The postulated sequence of capabilities was investigated from both the chemical context (CPT) and the non-chemical context (GPT). Average item difficulties associated with each of the five sections of the GPT forms are presented in Table XVII.

These results do not reflect any overall hierarchical pattern with respect to item cluster difficulties associated with the proportionality items. As expected, the combined direct and inverse proportionality items proved the most difficult, while conversion-type items proved the least difficult. However, findings remain inconclusive with respect to relationships which may exist between other proportionality-type questions.

Examination of average difficulties of parallel proportionality-type questions on the Chemistry Proportionality Subtests (CPT) revealed a more definite pattern. Table XVIII presents the average difficulty indices for the three types of proportionality questions, conversion, ratio, and direct proportionality, incorporated into the four CPT subtests. It should be noted that this analysis does not include inverse proportionality items as those topics which directly involve inverse

TABLE XVII

Average Difficulty Indices for General Proportionality Test Sections GPT(A) and GPT(B)

Test Type	Pretest GPT (A)	Posttest GPT (B)
1. Conversion (2)	.86	.97
2. Ratio (2)	.67	.73
3. Direct (4) Proportionality	.79	.56
4. Inverse (3) Proportionality	.66	.76
5. Combined (1)	.47	.44

( ) = number of items/subtest.

TABLE XVIII

Average Difficulty Indices for

Chemistry Proportionality Subtests

CPT(1), CPT(2), CPT(3), CPT(4), CPT(T)

N = 168

Type Test	CPT(1)		CPT(2)		CPT(3)		CPT(4)		CPT(T)	
	# of Item	Av. Diff.	# of Item	Av. Diff.	# of Item	Av. Diff.	# of Item	Av. Diff.		
Conversion	1	.77	1	.82	8	.68	2	.79	12	.76
Ratio	11	.71	8	.67	3.	.61	6	.72	28	.67
Proportionality	3	.49	2	.47	7	.58	7	.45	19	.49
TOTAL	15		11		18		15		59	

relationships in chemistry (e.g. solution chemistry) are not part of the Chemistry 10 program. The classification of particular CPT subtest items corresponding to proportionality items is included with the test statistics for each subtest in Appendix F.

Of the 59 items on the CPT(T) indicated in Table XVIII, 12 were considered to be conversion-type, 28 ratio-type and 19 of the direct proportionality-type. Understandably, particular subtests tended to be more closely associated with certain proportionality-type items. For example, the majority of conversion-type items (75%) are included in the CPT(3) dealing with mass to mole and mole to mass transformations. Ratio items dealt mainly with nomenclature, CPT(1), and ratio applications to chemical reactions, CPT(2). The majority of direct proportionality items are found in the area of gravimetric stoichiometry, CPT(4), and to a lesser extent, calculations concerning the mole, CPT(3).

Differences in difficulty levels associated with the three proportionality types are consistent with the hypothesized 'conversion - ratio - direct proportionality' hierarchy. Although these findings are suggestive of an underlying difficulty hierarchical framework, at least with respect to the proportionality items in chemistry, any conclusions based on this limited investigation must remain tenuous.

Question 2. Sex Factor

The second related question states: "Is there a significant relationship between sex and cognitive level for the study sample? Table XIX presents the sample distribution by sex and cognitive levels. A significant relationship was noted between sample sex and cognitive level ($\chi^2 = 17.3$, df = 3, $p < .001$). Only 19 male students (11.4%) were

TABLE XIX

Distribution of Sample by Sex and Cognitive Level

N = 168

Sex	Concrete (C)	Transitional (T)	Early Formal (F1)	Late Formal (F2)	Total
Male	19	21	21	29	90
Female	36	18	16	8	78
TOTAL	55	39	37	37	168

$\chi^2 = 17.3$, df = 3, $p < .001$

considered concrete in their thinking compared to 36 (21.4%) for the female students. Further, 17.2 per cent of the male sample were categorized as late formal (F2) compared to only 4.7 per cent for the female group.

Other studies which have reported a significant relationship between cognitive level and sex have included those of Herron (1975), Hobbs (1972) and Field and Cropley (1968). Herron in his investigation with freshmen college students noted that a larger proportion of boys exhibit formal thought than do girls, and Field and Cropley (1968) working with 218 students (mean age of 16 years, 10 months) also found a significant sex factor according to cognitive level, based on Piagetian clinical tasks. Hobbs (1972) studying 906 students in grades 7 to 12 found boys performed better than girls on tests of volume conservation and on the law of displacement.

Discussion

A general discussion of the findings of the present study is now undertaken. Following this, a section on problem solving in chemistry directed towards the practicing classroom chemistry teacher is presented. The chapter concludes with a summary of the results.

A major finding of the present investigation has to do with the confirmation of the formal nature of the proportionality schema itself. Data on the cognitive categorization of the sample are in general agreement with other studies (Lawson and Renner, 1974; Lawson, 1973; Higgens-Trenk and Gaite, 1971; Dale, 1970; Field and Cropley, 1968) which indicate that as many as 50 per cent of senior high school students are non-formal in their thinking. While few have challenged

Piaget's contention that proportionality must await formal operational thought, the majority of research in this area (e.g. Lovell, 1961) has involved either replicative work using the "classical" experiments (Inhelder and Piaget, p. 107-224, 1958) or modifications of Piagetian tasks based on physical phenomena (e.g. Hobbs, 1975; Bredderman, 1973). The present study related such schema directly to the science curriculum by investigating their manifestation in selected areas in introductory high school chemistry. Significant relationships noted suggest that chemical proportionality, like metric proportionality, is an intrinsically higher level of ordering experience, involving the matching of relations. Findings revealed that a sizeable proportion (over 20 per cent) of students studied chose an additive reasoning mode in solving selected proportionality tasks. This needs to be interpreted in view of the formal nature of the proportionality schema itself. That is, it may be that an additive strategy reflects the only reasonable means, relatively free of abstraction, whereby the non-formal thinker can achieve a degree of success on proportional reasoning tasks on a fairly reliable basis. In instances where additive modes prove inadequate, it would appear that 'success' must await the development of formal thought.

Findings also suggest that various aspects of proportional reasoning are not available equally to the respondent in all situations. As Lunzer (1965) has pointed out, both the content and nature of the problem, as well as its structure, are important in instances where

formal thought is required.

Although not investigated in the present study, tasks involving the application of inverse proportionality (e.g. in volumetric stoichiometry) may well place more serious demands on students than do simple conversions or ratio problems (Lunzer and Pumfrey, 1966). Further, the identification of a secondary factor associated with the proportionality schema in a Piagetian task sense, as opposed to more normal paper and pencil achievement measures involving proportions (CPT), appears to reinforce the importance of the relationship between the schema and the nature of the problem presented.

The apparent low transferability encountered between general proportional reasoning ability and proportional reasoning in a chemistry context was not altogether unexpected. The ability of some students to hastily compute a rather complex proportionality problem in a common context seems to bear little relationship to other tasks, seemingly involving similar demands in proportional reasoning, that may be encountered in the context of chemistry. It is as if the unfamiliar chemical context functions as an interfering agent, often preventing the student from reasoning in a more normal, logical manner.

We turn now to a consideration of a number of observations associated with proportional reasoning in relation to problem solving in chemistry as this pertains more directly to the classroom teaching situation.

Problem Solving in Chemistry

Topics explored in this concluding section include mole relationships, student interpretations of chemical equations, and the use of

dimensional-analysis in gravimetric stoichiometry. For illustrative purposes selected items drawn from the multiple-choice and open-ended sections of the CPT subtests are cited in relation to each area. The quoted figures appearing below each question refer to response patterns (in proportions) of an ALCHEM sample (left, N = 185) and a CHEM Study sample (right, N = 62). The correct response is denoted by an asterisk and percentages of students not attempting items are not included.

Mole relationships. In their preliminary study on the understanding of mole relationships in chemical calculations, Duncan and Johnstone (1973) reported significant differences between student performance on questions which involved straightforward 1:1 relationships and those which exhibited non-1:1 mole relationships. Analysis of items involving similar relationships in the present investigation revealed no significant difference between student achievement on these two types of questions. That is, both 1:1 relationships and non-1:1 relationships presented little difficulty to the students. Examples of 1:1 mole relationship items included the following:

CPT(3) Item 4

Given that:

$$Mg + S \rightarrow MgS$$

What mass in grams of Mg would react completely with 32 g (1 mole) of S?

	Answers	ALCHEM	Chem Study
A	12	.03	.00
*B	24	.67	.71
C	32	.22	.26
D	56	.05	.03

and

CPT(3) Item 12

Given that:

$$S + O_2 \rightarrow SO_2$$

What mass in grams of O_2 is required to react with 1/2 mole of S?

	Answers	ALCHEM	Chem Study
*A	16	.80	.85
B	24	.02	.03
C	32	.13	.10
D	48	.03	.02

Items involving non-unity mole relationships were equally well done. For example:

CPT(3) Item 3

Given that:

$$2KOH + H_2SO_4 \rightarrow K_2SO_4 + 2H_2O$$

How many moles of H_2SO_4 are required to react with 1 mole of KOH?

	Answers	ALCHEM	Chem Study
*A	1/2	.65	.63
B	1	.17	.10
C	2	.12	.27
D	4	.02	.00

and

CPT(3) Item 16

Given that:

$$N_2 + H_2 \rightarrow NH_3$$

Calculate how many moles of H_2 would react completely with 1 mole of N_2.

	Answers	ALCHEM	Chem Study
A	1	.10	.23
B	2	.11	.08
*C	3	.72	.61
D	4	.02	.08

Duncan and Johnstone (1973) further reported that equation balancing constituted a 'real' problem for introductory chemistry students with only just over 50 per cent of their sample (N = 273) able to balance an equation of the form, $2Al + 3O_2 \rightarrow Al_2O_3$. Contrary to Duncan and Johnstone's finding, balancing of chemical equations in the present study was not identified as a problem area. Items measuring students' ability to correctly balance equations had high difficulty indices indicating that the majority of students were successful on these items.

For example:

CPT(2) Item 6

$$\_NaOH + \_Al(NO_3)_3 \rightarrow \_Al(OH)_3 + NaNO_3$$

Balance the above equation using simplest whole numbers. The coefficient (number in front) for $Al(NO_3)_3$ would be:

	Answer	ALCHEM
*A	1	.88
B	2	.02
C	3	.10
D	4	.00

and

CPT(2) Item 2

Sulfuric acid + aluminum hydroxide → water + aluminum sulfate

a. $H_2S + Al(OH)_2 \rightarrow HOH + AlSO_4$

b. $HSO_4 + AlOH \rightarrow HOH + AlSO_4$

c. $3H_2SO_4 + 2AlH_3 \rightarrow 6H_2 + Al_2(SO_4)_3$

d. $3H_2SO_4 + 2Al(OH)_3 \rightarrow 6HOH + Al_2(SO_4)_3$

Answer	ALCHEM
a	.04
b	.08
c	.07
*d	.80

It should be noted here that as CPT(2), 'Chemical Reactions', was not felt to be relevant to the CHEM Study sample, no representative items are available to assess the degree of difficulty of balancing equations for this sample of students. However, for the ALCHEM sample, equation balancing appeared to pose little difficulty. The average difficulty index for the 5-item cluster involving the balancing equations on CPT(2) for the ALCHEM sample was 0.76. While balancing problems, taken in isolation, appear to present little difficulty for the students, in more complex stoichiometry questions, where a balanced equation represents a fundamental step, failure to correctly balance the equation may prove a major source of error.

Interpretations of chemical equations. Analysis of the open-response question in the CPT subtests revealed considerable misunderstanding surrounding the chemical interpretation of an equation, in spite of the apparent lack of difficulty over the balancing of equations noted above.

For example, in assessing students' perception of a balanced chemical reaction the following question was asked:

CPT(2) Question 2

One student maintains that the correct chemical interpretation of the reaction below is that one atom of A reacts with 4 atoms of B to form one molecule of AB_4.

His friend claims that a more accurate statement would be, one *mole* of A reacts with 4 *moles* of B to form one *mole* of AB_4. Are either (or both) of these interpretations correct? Discuss your answer.

(equation)	A	+	4B	→	AB_4
Student 1	one atom	+	4 atoms	→	one molecule
Student 2	one mole	+	4 moles	→	one mole

Only 35 per cent of the main study ALCHEM sample (N = 168) felt

that both interpretations presented were valid. Typical explanations included:

> "Both are correct, since a mole is simply the number of molecules of each substance times "6.02×10^{23}." But student 2 is probably more correct, since such reactions will probably take place with such high numbers."

Thirty-nine students (23.2%) felt that the 'micro' or atomic chemical interpretation presented by student 1 was the most accurate:

> "Student 1 is right because there is only 1 molecule in that part of the formula, there isn't one mole."

> "Student one is correct because you are dealing with molecules and atoms, not with moles."

Forty-five students (26.8%) chose the 'macro' or molar interpretation presented by student 2:

> "Yes, student 2 is the most correct one because the moles are more accurate."

> "The Student 2's argument would be correct because the coefficients represent moles, or rather $4 \times 6.02 \times 10^{23}$ atoms of B & $1 \times 6.02 \times 10^{23}$ atoms of A."

Surprisingly, ten students (6%) questioned the authenticity of both interpretations because of their lack of understanding of how the product in each case (either molecules or moles) could be unity. For example:

> "Neither are correct because 1 atom + 4 atoms equals 5 atoms, and one mole + 4 moles = 5 moles not 1."

> "Neither answer is right because in the first one you don't use atoms and in the second one you would get 5 moles."

Notwithstanding this, it is evident that a considerable proportion of students failed to realize the 1:1 correspondence between atoms and molecules and moles of atoms and molecules. For these students, it appears as though the mole is a conveniently contrived concept which bears little or no relationship to the reality of the chemical reaction

itself. This inability to perceive the basic 1:1 proportionality underlying much of chemistry may account for a large portion of the difficulty encountered by students in their efforts to apply the mole concept in problem situations. This problem may be related to the earlier section on the balancing of equations. While students have little difficulty arriving at the correct coefficients for a balanced equation, only about one-third seem to have an adequate understanding of its significance. Many students seem baffled by equations in which a given number of moles of reactants yields fewer (or greater in some cases) moles of products. This apparent discrepancy in the minds of some students may be symptomatic of far deeper misunderstandings associated with conservation concepts in elementary chemistry. Hall (1973), for example, in an investigation carried out with 11 to 12 year old children, using techniques analogous to those of Piaget, found that even after the completion of an introductory course in chemistry over a nine month period, conservation (i.e. conservation of chemical identity, composition and mass) had not been attained by a considerable proportion of subjects (e.g. 43 per cent failed to conserve composition). Students' conceptions of chemical reactions may well presuppose the prior existence of basic schemata like those studied by Hall. In the light of present findings, areas involving the application of equations in introductory chemistry might be re-examined. The development and review of certain necessary prerequisite schemata may prove to be an effective approach in introductory chemistry.

Dimensional-analysis. Another important area related to the present investigation has to do with the use and effectiveness of the

so-called unit or dimensional-analysis technique. Dimensional-analysis refers to the commonly used strategy whereby unit factors or dimensions are utilized in converting a measure in one unit to an equivalent measure expressed in another unit. For example the calculation of the number of seconds in one year could proceed through dimensional-analysis as follows:

1 year x 365 days/year x 24 hours/day x 60 minutes/hour x 60 seconds/minute = 31,536,000 seconds.

Each step in the process makes use of the units (i.e. dimensions) as 'checks' to ensure that the conversion is performed correctly. One problem however in the use of dimensional-analysis, as noted by Herron (1976), is that it normally involves several steps without closure at the end of each logical step. To illustrate using the above example, the only effective closure occurs at the end of the four steps in the problem. According to Herron there is some evidence (Collis, 1971) to indicate that the non-formal student is unable to handle this lack of closure. The decision to include dimensional-analysis in the present discussion was made largely on the basis of this contention and other factors concerning its relative effectiveness in solving problems in chemistry. That is, does dimensional-analysis prove more effective than, say, a traditional proportionality approach to stoichiometry? At what stage should dimensional-analysis be used?

Dimensional-analysis represents a central methodology underlying the major approach to problem solving in the ALCHEM Chemistry 10 materials. Dimensional-analysis is not emphasized as an instructional strategy in the CHEM Study program. For example, in ALCHEM stoichiometry

calculations, four main steps are advocated:

STEP I: Write the balanced chemical equation:

$$2\ A + B \rightarrow 2C$$

STEP II: Convert mass of substance A (starting substance) to moles.

$$\text{moles of A} = \frac{\text{mass of A}}{\text{molar mass of A}} = \frac{\text{grams}}{\text{grams/mole}}$$

STEP III: Use the coefficients in the balanced equation to determine the number of moles of B (desired substance) needed to combine with the moles of A (starting substance) calculated in Step II.

$$\frac{\text{moles of B (desired substance)}}{\text{moles of A (starting substance)}} = \frac{1}{2}$$

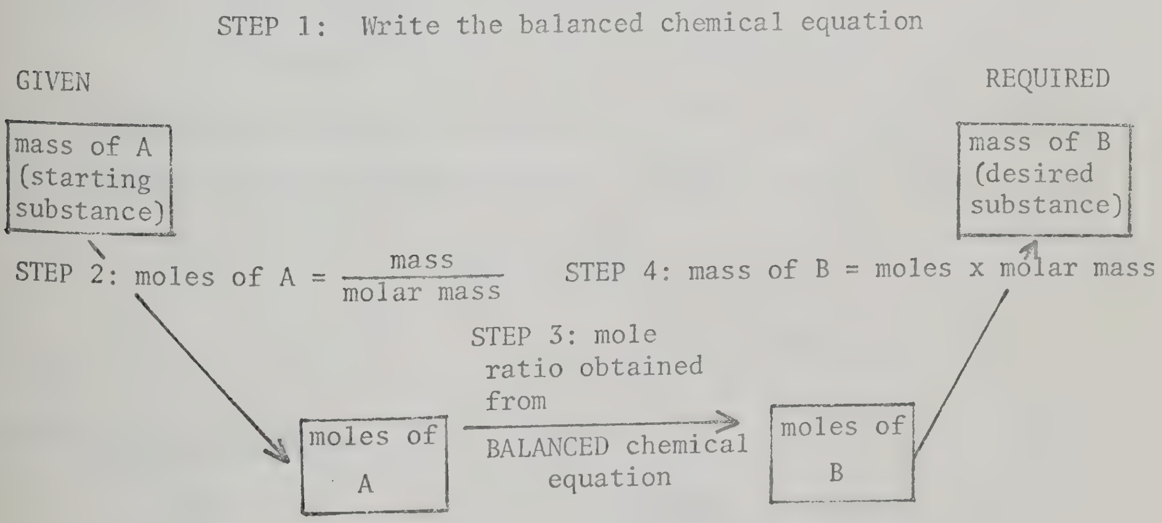
or, in this case,

$$\text{moles of B (desired substance)} = 1/2 \times \text{moles of A (starting substance)}$$

STEP IV: Convert moles of B to mass of B.

$$\text{mass of B} = \text{moles of B} \times \text{molar mass of B}$$
$$= \text{moles} \times \text{grams/mole}$$

The four general steps are summarized in the following STOICHIOMETRY FLOW CHART:


STEP 1: Write the balanced chemical equation
GIVEN
REQUIRED
mass of A (starting substance)
mass of B (desired substance)
STEP 2: moles of A = mass / molar mass
STEP 4: mass of B = moles x molar mass
STEP 3: mole ratio obtained from BALANCED chemical equation
moles of A
moles of B

In the present study certain questions found in the open-ended sections of CPT(3) and CPT(4) were analyzed for the two samples (ALCHEM, N = 168 and CHEM Study, N = 141) separately, in an attempt to ascertain

to what extent dimensional-analysis was applied and its relative effectiveness. Question 2 on CPT(4) illustrates a stoichiometric problem studied:

Question 2

Determine the number of *grams* of carbon produced from the complete decomposition of 176 g of carbon dioxide.

Seventy-two per cent (72.0%) of the ALCHEM sample were considered successful on the problem compared to forty-eight per cent (48%) of the CHEM Study sample.

The majority of students in the ALCHEM sample (over 90 per cent) tended to apply a dimensional analysis approach to problems by following the stoichiometry flow chart. For example:

Sample ALCHEM solution:

1) $1CO_2 \rightarrow 1C + 1O_2$

2) $\frac{176}{44\ \text{mol}} = 4.0$ moles of CO_2

3) 1/1 x 4.0 moles = 4.0 moles of C

4) 4.0 moles x 12 gmol = 48.0 grams of carbon

About 60 per cent of the successful CHEM Study students either set up a proportionality expression based on the mole ratio, e.g.:

$$\text{moles} = \frac{176}{44}$$

$$\frac{1}{4} = \frac{12}{X} \qquad X = 48\ \text{gms [sic]}$$

or directly applied the mole definition, e.g.:

CO_2 $\qquad$ $\text{xmoles} = \frac{176\ \text{gms}}{44\ \text{gms/mole}} = 4\ \text{moles}$

C = 12 x 1 = 12
$O2$ = 16 x 2 = $\underline{32}$
44

$$4\ \text{moles} = \frac{x\ \text{gms}}{12\ \text{gms/mole}} \quad = \quad 48\ \text{gms of carbon produced.}$$

Only 10 per cent of the CHEM Study sample included a balanced equation for the reaction in their responses.

As suggested by Herron (1975), there appears to be a relationship between the effectiveness of dimensional-analysis and cognitive level. For example, on the problem described above well over half (64%) of the 55 students in the main study sample (N = 168) classified as concrete thinkers responded correctly. It may be that dimensional-analysis represents a less demanding approach to chemical problem solving than other strategies which require the application of proportional reasoning. That is, the algorithm advocated in dimensional-analysis necessitates that students specify all the parameters of the stated problem, including the relevant balanced equations. This may tend to minimize the number of careless and unnecessary errors; in this sense dimensional-analysis operates as a bookkeeping device. The process may, of course, increase the possibility of error as the number of intermediate steps increases. Whether the process of actually performing the step-by-step procedure itself assists in the conceptualization of the problem as opposed to the efficacy of the concept of dimensional-analysis *per se* remains contentious at this time. In any case it is unlikely that dimensional-analysis has any negative effect on students' perception of relationships inherent in many problems in introductory chemistry. In spite of the limited basis for these preliminary findings, dimensional-analysis is endorsed as a possible means of alleviating or at least reducing some difficulties in proportional reasoning encountered by students who are not yet formal operational in their thinking.

The following brief concluding section presents a summary of the major findings of the present investigation.

Summary of Results

General findings associated with the major hypotheses in the present study identified significant relationships between proportional reasoning in chemistry (CPT) and (i) chemistry achievement (CAT), (ii) cognitive level (PT), and (iii) proportional reasoning in a non-chemistry context (GPT). Instruction in proportional reasoning in chemistry did not appear to enhance general proportional reasoning ability. Regression analysis to predict chemistry achievement (CAT) found only the chemistry proportionality subtests significant predictor variables. A principal-factor solution identified three main factors. The chemistry proportionality subtests and the chemistry achievement criterion (CAT) loaded heavily on the first factor, while the second factor was associated with the four Piagetian tasks used in the study and served to distinguish the proportionality tests from the set of Piagetian tasks. This secondary factor appeared to substantiate an earlier similar finding noted by Bart (1971). The third factor contained high loadings for the verbal reasoning and verbal analogy sections on the pretest, GPT(A) and posttest, GPT(B), forms of the General Proportionality Test, and was interpreted as a further indication of the statistical equivalency of these instruments.

Approximately 50 per cent (48.9%) of the total sample (N = 309) were found to be capable of formal thought based on performance on four Piagetian tasks while about one-third (28.8%) were still considered to be limited to concrete operations. Results of analyzing

the nature and extent of student responses revealed the existence of a prevalent additive mode of reasoning, associated with concrete operational thinkers, with respect to selected proportionality tasks.

Related findings failed to detect a hierarchical structure associated with general proportional reasoning. However, results relating to proportional reasoning in a chemistry context supported the hypothesized sequence of capabilities. A significant relationship in favor of the boys was noted between sex and cognitive level.

The concluding section of the chapter focussed on three areas of problem solving in chemistry related to proportional reasoning: mole relationships, interpretations of chemical equations and the use and effectiveness of dimensional-analysis. A number of observations directed toward the classroom chemistry teacher were offered.

Chapter V

SUMMARY, IMPLICATIONS AND RECOMMENDATIONS

In this final chapter, a summary of the investigation is presented, followed by a discussion of the implications for classroom science teaching. Finally, a number of recommendations for further research are outlined.

Summary

The purpose of the present study was to ascertain the extent to which students' perceptions of the proportionality schema are related to achievement in introductory chemistry. A total of 309 Grade 10 students enrolled in four Edmonton senior high schools was tested under normal classroom conditions. The total sample consisted of i) a main study sample (N = 168) comprising students studying the Alberta Chemistry (ALCHEM) Chemistry 10 materials and, ii) a second study sample (N = 141) consisting of students enrolled in the CHEM Study version of the Chemistry 10 program.

Four main test instruments were administered during the 1976 spring semester. A set of four collectively administered Piagetian tasks (PT) served as a measure of students' cognitive functioning level. Two forms of a General Proportionality Test, GPT(A) and CPT(B), served to indicate students' performance on general proportional reasoning.

A Chemistry Proportionality Test (CPT) consisting of four subtests in two sections dealt with the following topics: 'nomenclature and the writing of formulae' CPT(1), 'chemical reactions,' CPT(2), the 'mole concept' CPT(3), and 'gravimetric stoichiometry' CPT(4).

The Chemistry Achievement Test, CAT, covering all sections of the Chemistry 10 program, was used as a measure of general achievement in

chemistry. The four Piagetian tasks (PT) used were: the Balance Problem (BP), the Ratio Task (RT), Metric Puzzle (MP) and the Islands Puzzle (IP), and these formed the basis for the categorization of the total sample (N = 309) into respective levels of concrete, transitional and formal thought.

The Piagetian Tasks (PT) were administered prior to the commencement of instruction in chemistry, followed by the GPT(A) during regular classroom periods. Subtests of the Chemistry Proportionality Test (CPT) followed the conclusion of each appropriate unit throughout the semester period. At the conclusion of the semester, all main study students (N = 168) were administered the alternate form of the General Proportionality Test, GPT(B), followed by the CAT. Both the CPT subtest and CAT scores were used by the seven cooperating teachers in their regular evaluation of the chemistry course.

Student responses to each Piagetian task were evaluated in view of criteria considered indicative of concrete and formal thought, based on *The Growth of Logical Thinking* (for the Balance Problem [BP]), and other research studies of Karplus et al. (1974) and Collea (1975) (the Ratio Task [RT], the Metric Puzzle [MP], and the Islands Puzzle [IP]). Three of the tasks, i.e., the Balance Problem, the Ratio Task and the Metric Puzzle, involved direct aspects of the proportionality schema while the Islands Puzzle was viewed as a more general indicator of formal operational thought.

In terms of cognitive functioning, the total study sample (N = 309) was classified as: concrete operational, 89 students (28.8%); transitional, 69 students (22.3%); early formal, 84 students (27.2%), and late formal, 67 students (21.7%). In gross terms, 151 students (48.9%) were found to be

capable of using formal operations in their thinking with respect to the four tasks with 89 students (28.8%) still limited to concrete operations. The remaining students (22.3%) were deemed to be at an intermediate or transitional level of thought.

The main study sample (N = 168) was divided into three nearly equal achievement groups (high, middle and low) on the basis of performance on the CAT. One-way analysis of variance revealed that the three achievement groups were significantly different with respect to each of the following study variables: GPT(A), GPT(B), PT, CPT(1), CPT(2), CPT(3) and CPT(4).

Significant correlations were found to exist between proportional reasoning in chemistry (CPT) and (i) achievement in chemistry (CAT), (ii) cognitive level (PT) and (iii) proportional reasoning in a non-chemistry context (GPT). A stepwise regression analysis carried out for the prediction of achievement in chemistry revealed that the chemistry proportionality subtests were the only significantly contributing predictor variables accounting for 63.4 per cent of the total variance of the chemistry achievement test (CAT) scores.

Results of a principal-factor solution performed on the intercorrelation matrix of eighteen study variables identified three main factors. The proportionality subtests, CPT(1), CPT(2), CPT(3), CPT(4) and the achievement criterion, CAT, loaded heavily on the first factor. The existence of a secondary factor associated with all four Piagetian tasks, BP, RT, MP and IP, was noted to be similar to a finding reported by Bart (1971) on the bifactor structure of formal thought. The third factor, containing heavy loadings for the verbal reasoning and verbal analogy sections of the two forms of the General Proportionality Test, GPT(A) and

GPT(B) was interpreted as a further indication of the statistical equivalency of these pretest and posttest instruments.

Chi square tests of independence performed on the relationships between cognitive level, as measured by the PT, and chemistry achievement (CAT) categorized as high, medium, and low, proportional reasoning in chemistry (CPT), and general proportional reasoning (GPT) were significant (χ^2 = 47.7, 59.2, 59.5, respectively, df = 6, $p < .001$). A significant relationship in favor of boys was also noted between sex and cognitive level.

Although there was little evidence found to support a postulated hierarchy associated with general proportional reasoning, results relating to proportional reasoning in chemistry generally supported the hypothesized sequence of capabilities. A number of observations in relation to problem solving in chemistry as they pertain more directly to the classroom teaching situation were also noted. Recommendations based on preliminary findings regarding mole relationships, interpretations of chemical equations and the use of dimensional-analysis were offered.

Implications for Classroom Science Teaching

The relationship between proportional reasoning in chemistry and cognitive level of development suggests a number of implications for the practising high school chemistry teacher. On the basis of general findings in the present investigation, it is suggested that an assessment of students' cognitive functioning level be attempted before the commencement of instruction in chemistry. The type and format of the measures used to assess the cognitive level of subjects in this study (Balance Problem [BP], Ratio Task [RT], Metric Puzzle [MP] and the Islands Puzzle [IP]) are all

appropriate to the context of a science class and could be administered with relatively little difficulty before chemistry instruction commenced. For example, the set of tasks in booklet form could serve as a relevant introductory laboratory exercise in Chemistry 10. Tasks used have both direct curriculum application (e.g. the balance problem and the ratio task set in a chemical context) and current interest (e.g. the metric conversion puzzle). As such they offer a relatively unobtrusive means to the assessment of cognitive development. Rowell and Hoffman (1975) have shown that it is possible to produce workable, reliable group forms of Piagetian tasks which can be readily administered and assessed. Given adequate instruction on scoring techniques, classroom teachers could categorize students on selected tasks for diagnostic purposes. The early broad assessment, for example, of each student's cognitive level could provide an opportunity to discuss with students the application and importance of the proportionality schema to selected areas in chemistry. Students' solutions to the tasks may also prove insightful to the science teacher in identifying preferred student problem solving approaches and strategies. Teachers would, of course, have to be made fully aware of the dangers of over-specification or of becoming overly rigid in their categorization of task performances in order to avoid any longlasting derogatory effects associated with the labelling of students and the ensuing expectations of performance which may be generated.

The approach used in assessing proportional reasoning in the present study also seems to lend itself well to a review of other related areas in science which involve proportionality (e.g. density, concentration, velocity). Exercises and programmed materials involving proportional reasoning at both

concrete and formal levels could also be developed to allow the student to enter the review process at his or her level. Parallel examples drawn from general, everyday applications of proportionality similar to those found in the GPT items might also be used to provide greater insight into the nature of the relationship between proportional reasoning in selected areas of science and general proportional reasoning. Although there are a number of unanswered questions concerning this relationship in the present study, findings do suggest that it would be highly erroneous to assume terms like 'density,' 'concentration,' 'reaction rate' are clearly understood by senior high school students.

Students operating at the concrete or transitional levels may benefit from a laboratory approach involving 'concrete' situations in which they can manipulate certain variables to study proportionality aspects inherent in many chemical systems. The introduction, for example, of a number of straightforward reactions using elements and compounds easily handled in the laboratory (e.g. the formation of copper II sulfide from its respective elements) could prove advantageous in introducing gravimetric stoichiometry and the concept of a 'limiting reagent.'

Stoichiometric examples (e.g. certain gaseous reactions) which are more removed from the students' experience might be better left until greater exposure to more realistic, concrete instances is gained. Laboratory exercises concerning the mole and its application to both qualitative and quantitative stoichiometry could be included in introductory chemistry in an effort to bridge the gap between theory and classroom practice. One questions, for example, in spite of the heavy emphasis given to the mole at this level, how many students have actually had the opportunity of

weighing out a number of common molar quantities or have performed laboratory exercises involving Avogadro's number in an effort to gain some appreciation of the magnitude and significance of the number, 6.02×10^{23}.

An awareness of the extent to which the proportionality schema pervades the curriculum could prove useful to the classroom teacher in devising instructional strategies to overcome or at least minimize difficulties in selected areas in chemistry. The varied 'mass to mass' and 'mass to mole' transformations associated with mole conversions might be more heavily emphasized by including supplementary problems not usually found in existing programs. Perhaps a larger number of non-1:1 stoichiometric relationships could also be presented than is the practice at present. Although non-1:1 molar relationships are undoubtedly mentioned in introductory chemistry, typical illustrations and test questions tend to be associated with simple chemical reactions involving 1:1 or small whole number relationships. The finding that up to one-fourth of the sample in the present study used an additive reasoning approach in solving selected proportionality problems may be related to the complexity of the actual ratio inherent in the problem itself. The tendency of students in the present study to apply 1:1 molar relationships in inappropriate situations is understandable if examples of non-1:1 relationships were rarely met in the classroom. A variety of chemical reactions illustrating as many types of molar relationships as possible should be introduced to students as a basis for stoichiometric calculations rather than any emphasis on other aspects of chemistry, e.g. reaction types, or reaction mechanisms.

The use of a dimensional-analysis approach to stoichiometry is endorsed both from a methodological viewpoint and as one which promotes sound

problem-solving habits. Dimensional-analysis appears to be a process which is easily understood by students independent of cognitive functioning level. Although the danger of thoughtless or rote application of the process exists, the procedure is useful in that it at least organizes the material in such a manner that the student may be led to an understanding of the relationships involved.

The identified sequence of capabilities, 'conversion - ratio - direct proportionality,' with respect to proportional reasoning in chemistry could prove useful to the classroom teacher as a natural order of succession leading to more complex proportionality applications. For example, following mastery of chemical conversions, application to balanced chemical equations through the use of mole ratios could be attempted. A number of direct proportionality applications, such as the 'mass to mass' problems found in gravimetric stoichiometry, would then follow logically. Although not dealt with in the present investigation, instances of inverse proportionality (e.g. in solution chemistry) may represent more complex levels in a hierarchy that may be associated with the proportionality schema.

In such instances mastery of lower levels in a hierarchy would appear prerequisite to proceeding to the next level. Students should be encouraged to offer explanations for chemical phenomena in order to assess their interpretations for chemical authenticity. For example, the erroneous interpretation held by many students in the present study as to the meaning of chemical equations might have been averted if the misconceptions could have been identified and discussed.

Recommendations for Further Research

As a result of the present investigation, possible future research activities include the following:

1. The General Proportionality Test (GPT) as used in the present study, requires further development. Revisions based on present findings, together with further administrations of the GPT, might be undertaken to further refine the instrument and substantiate its reliability and discriminability. This could lead to replications of the present study at other levels of science instruction. For example, test instruments similar to the GPT and CPT could be devised at other high school grade levels to investigate proportionality in other areas of chemistry (e.g. volumetric stoichiometry, reaction rates, chemical equilibrium). The present approach could also be used to identify areas of science at the junior high level such as density and specific gravity which rely on the proportionality schema.
2. The effect that various instructional strategies have on the prevalence of proportional reasoning capabilities should be investigated. Findings associated with the additive mode of reasoning identified in the present study seem sufficiently prevalent to warrant further investigation. Additive reasoning could be studied in relation to: (i) mode of acquisition, (ii) task dependency, and (iii) cognitive level.
3. A longitudinal study on the evolution of proportionality schema should be undertaken, covering the transitional span between concrete and formal operational thought. Insight into the

development of the schema over a prolonged period (e.g. Grades 6 through 12), in relation to curricular demands, could prove invaluable to both science and mathematics teachers in relation to grade level placement or related concepts.

4. The relative effectiveness of various teaching approaches to selected concepts involving proportional reasoning in chemistry could be examined. Those proportionality competencies in chemistry judged accessible to concrete thinkers and those accessible only to post-concrete thinkers could be presented at appropriate levels of abstraction. Methodological outcomes of each approach could then be evaluated. The effectiveness of a dimensional-analysis approach across cognitive levels could also be assessed in this manner.

5. Validation procedures together with certain refinements with respect to the group administered Piagetian tasks (PT) used in the present study should be undertaken. Revisions could include certain format and administrative changes associated with the set of tasks in addition to exploring other suitable tasks for inclusion. Cognitive level criteria based on a larger sample and cross-section of students for individual tasks across grade levels could prove extremely useful norms for future research and diagnostic work in this area.

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APPENDICES

APPENDIX A

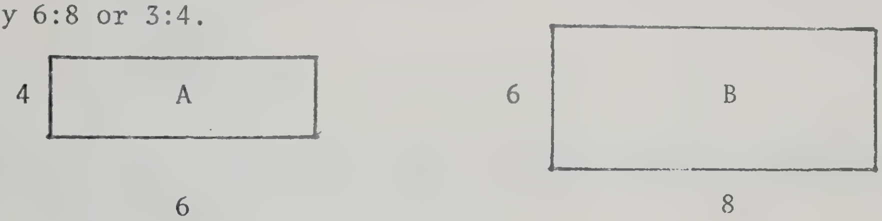
(GPT) - Form A

NOTE: THIS IS NOT A TEST IN MATHEMATICS BUT WE ARE INTERESTED IN HOW YOU ARRIVE AT SOLUTIONS TO THESE QUESTIONS. IT IS THEREFORE VERY IMPORTANT THAT YOU SHOW ALL YOUR WORK AND CALCULATIONS IN THE SPACES PROVIDED.

SECTION 1

This section contains 15 multiple choice items dealing with ratio and proportion as they might be found in common situations. Please place the letter which you feel corresponds to the correct answer on the answer sheet provided.

1. Below are shown two rectangles, A and B. The ratio of their lengths is given by 6:8 or 3:4.



The ratio of their widths would be given by:

A. 6:6
B. 6:9
C. 2:3
D. 3:2

2. The Canadian dime contains 10 per cent copper and 90 per cent silver by weight. The ratio of copper to silver by weight is therefore:

A. 9:1
B. 1:9
C. 8:9
D. 9:8

3. At one stage in the hockey season the Edmonton Journal reported the figures for the Edmonton Oilers and the Winnipeg Jets of the World Hockey Association as follows:

	Games	Won	Lost	Tied
Edmonton	60	31	26	3
Winnipeg	60	28	28	4

Which team had the better win to loss ratio?

A. Edmonton
B. Winnipeg
C. Both are the same
D. Insufficient information given.

4. Statistics Canada reports that the average Canadian family consumes 820 eggs per year. A certain family consumes 1.5 dozen (or 18) eggs per week. Relative to the national average, this family's consumption is:

A. above the national average
B. below the national average
C. Same as the national average
D. insufficient information given.

5. A 10 kilogram roll of wire (1 kilogram = 1000 grams) has a uniform weight along its length of 4 grams per centimetre. What is the length of wire in the roll?

A. 250 cm.
B. 2500 cm.
C. 10000 cm.
D. 40000 cm.

6. You have a 21 foot log and you need to cut it into two smaller logs unequal in length. The ratio of the lengths of the smaller logs must be 3:4. Where would you make the cut?

A. 3 feet from one end
B. 4 feet from one end
C. 7 feet from one end
D. 9 feet from one end

7. Simpsons Sears charges $1.05 for 20 lb. of nails, W.W. Arcade charges 88 cents for 16 lb. of nails, while B. Lumber charges 50¢ for 10 lbs. of nails. Which is the best buy?

A. Simpsons Sears
B. W.W. Arcade
C. B. Lumber
D. Insufficient information given.

8. The ratio of an object's weight on Earth to its weight on Neptune is 5:7. The weight of an Astronaut on Earth is 180 lbs. What would his weight be on Neptune, if he could get there?

A. 128.6 lbs.
B. 252 lbs.
C. 900 lbs.
D. 1260 lbs.

9. A T.V. screen is rectangular in shape. Its size is usually given as, say, 20 in. This is the length of the diagonal of the rectangle. The area of the screen varies as the square of its linear measurements. The area of a 20 in. screen is 190 square inches. What is the area of a 24 in. T.V. screen?

A. 158.3 in.
B. 228 in.
C. 400 in.
D. 576 in.

10. In class 10B there are 30 students. There are 3 girls to every 2 boys in the class. How many boys are there in class 10B?

A. 12
B. 18
C. 20
D. 24

11. A weight placed on the end of a spring stretches the spring in direct proportion to the weight. A weight of 15 grams stretches the spring 4 cm. An object stretched the spring 12 cm. What is the weight of the object?

A. 27 grams
B. 36 grams
C. 45 grams
D. 60 grams

12. A group of 50 students decide to hold a dance. They rent a dance hall for 360 dollars and agree to share the cost equally. After the agreement with the management of the hall has been signed, they decide to let another 40 students come to the dance. What will be the cost per atudent if they all share the total cost?

A. \$3.60
B. \$4.00
C. \$7.20
D. \$9.00

13. Eight men can build a pre-fab house in 9 days. How long will it take 24 men to build an identical house?

A. 2.6 days
B. 3 days
C. 18 days
D. 27 days

14. A certain project can be completed by 28 men in 90 days. The contractor wants to complete the project more quickly, in order to earn a substantial bonus. He hires extra men so that he can complete the project in 84 days. How many extra men did he hire?

A. 2
B. 3
C. 6
D. 30

15. A charity group wants to raise money by washing cars. On a trial run they find that 10 boys can wash 20 cars in 4 hours. How many boys are

required to wash 30 cars in 3 hours?

A. 15
B. 20
C. 25
D. 30

SECTION II

Questions 16 - 18 deal with the following:

Joe, Bill and John are friends. Joe is taller than Bill. Joe is shorter than John. Place the correct answer for each question on the answer sheet.

16. Bill is taller than John:

a) right
b) wrong
c) cannot say

17. John is taller than Bill:

a) right
b) wrong
c) cannot say

18. The tallest boy is:

a) Joe
b) Bill
c) John

Questions 19 and 20 deal with the following situation:

Consider A, B and C. If o means taller than, faster than, darker than, and x is its opposite, then we may write:

A o B
A x C

Now select the correct answer in each case.

19. B o A

a) right
b) wrong
c) cannot answer

20 C x B

a) right
b) wrong
c) cannot answer

Form A

Questions 21 - 30 consist of analogy questions involving both words and numbers. In each question you will find three capitalized words (or numbers) and in brackets, a group of four uncapitalized words lettered a, b, c and d. You are to select from the four uncapitalized words that word which best completes the analogy with the three capitalized words. In each case place your answer on the answer sheet.

For example:

TRIANGLE : SQUARE :: 3 :
a) 1
b) 2
c) 3
d) 4

The single colon between words means 'is to' and the double colon means 'as'. That is, TRIANGLE is to SQUARE as 3 is to ?

Since a triangle is a geometric figure which has three sides and a square is a geometric figure which has four sides, the correct choice is d) 4.

21. TON : POUND :: FOOT :
a) yard
b) shoe
c) toe
d) inch

22. KITE : BOAT :: FLY
a) swim
b) sail
c) skate
d) ski

23. 1/2 : 2 :: a) 1/3 : 2/3
b) 1/4
c) 1/5
d) 1/6

24. FIGHT : WAR :: ACT :
a) battle
b) song
c) play
d) tire

25. 37 : 6 :: a) 64 : 8
b) 65
c) 48
d) 56

Form A

26. 169 : 13 :: 121 :
- a) 9
- b) 10
- c) 11
- d) 12

27. LAKE : BATH :: WATERFALL :
- a) rain
- b) dive
- c) shower
- d) swim

28. 41 : 48 :: 13 :
- a) 89
- b) 20
- c) 18
- d) 27

29. WHEAT : FLOUR :: HIDE :
- a) leather
- b) fur
- c) skin
- d) pelt

30. MICROSCOPE : TELESCOPE :: GERM :
- a) astronomy
- b) astronaut
- c) star
- d) lens

Name______________________________

(GPT) - Form A

Class______________________________

In questions 31 - 34 place the correct number in the space provided. In each case EXPLAIN the reason for your choice.

31. The next number in the series is:

6, 15, 24, ☐

Explanation:

32. Determine the missing number:

3	6	7	10
12	24	28	☐

Explanation:

33. The next number in the series is:

4, 10, 28, 82, ☐

Explanation:

34. Determine the missing number:

3	7	4	8
15	35	7	☐

Explanation:

APPENDIX A

(GPT) - Form B

NOTE: THIS IS NOT A TEST IN MATHEMATICS BUT WE ARE INTERESTED IN HOW YOU ARRIVE AT SOLUTIONS TO THESE QUESTIONS. IT IS THEREFORE VERY IMPORTANT THAT YOU SHOW ALL YOUR WORK AND CALCULATIONS IN THE SPACES PROVIDED.

SECTION I

This section contains 15 multiple choice items dealing with ratio and proportion as they might be found in common situations. Please place the letter which you feel corresponds to the correct answer on the answer sheet provided.

1. Recent national census figures reveal that the total number of females in Canada exceeds the total number of males. Is the ratio of males to females in Canada

A. greater than one
B. less than one
C. equal to one
D. over 2

2. In a ten game curling bonspiel, the results for the top 4 contending teams after several rounds of play were as follows:

	games played	won	lost
Team A	9	6	3
Team B	9	8	1
Team C	8	7	1
Team D	8	6	2

Which team would be considered the most likely to win the bonspiel?

A. Team A
B. Team B
C. Team C
D. Team D

3. One of the top scorers in the city basketball league averages 10 baskets per game. To accomplish this he normally attempts about 20 shots on the basket each game. His shooting average expressed as a ratio would be:

A. 0.5
B. 2.0
C. 10
D. 20

4. A family of four reports that their monthly food bill is $150. What would the year's food cost for this family be?

   A. $150
   B. $600
   C. $1200
   D. $1800

5. The proud owner of a new compact car recently returned from a 1200 mile trip in which he claims to have averaged 25 miles per gallon of gasoline throughout. How many gallons did he use for the trip?

   A. 48
   B. 96
   C. 480
   D. 960

6. An electronic parts assembler, Tom is able to produce 4 complete units in 20 minutes. A second worker, Bill, assembles 3 similar units in 18 minutes, while a third, Jack, completes 11 units every hour. Who is the fastest worker?

   A. Tom
   B. Bill
   C. Jack
   D. insufficient information given

7. Two schools, Southern High snd Northern High, together send a total of 35 delegates to a national conference. The student enrolments in the schools are in the ratio 2 : 5. The number of delegates allowed to each school at the conference must be in proportion to the school enrolment. How many delegates should Southern High send?

   A. 10
   B. 15
   C. 20
   D. 25

8. A 6 oz. 'family' size of soap sells for 30 cents. The manufacturer decides to be fashionable and repackage his soap in a 21 oz. package and call it his 'jumbo' size. Contrary to accepted practice, he does not wish to raise his price. What should he charge for the jumbo size?

   A. 51¢
   B. $1.05
   C. $1.80
   D. $1.26

9. A recipe for orange punch requires that 5 cups of orange juice be mixed with 8 cups of water. How many cups of orange juice are needed to make 52 cups of punch?

   A. 13
   B. 20
   C. 26
   D. 40

10. The orange punch mentioned in Question 9 is consumed at a party. But each person at the party is allowed only 2/3 of a cup. How many people can be served?

    A. 35
    B. 52
    C. 60
    D. 78

11. A man drives from Edmonton to Saskatoon, a distance of 180 miles, in 8 hours. He then continues to Blaine Lake, a distance of 180 miles from Saskatoon. He is careful to keep his average speed for the two legs of the trip the same. How long did it take him to drive the second leg, i.e. from Saskatoon to Blaine Lake?

    A. 2.6 hours
    B. 3 hours
    C. 4 hours
    D. 6 hours

12. An actual distance of 210 km. is represented on a map by a length of 3 cm. Town A and Town B are 8 cm. apart on the map. What is the actual distance apart of Town A and Town B?

    A. 78.7 km.
    B. 560 km.
    C. 620 km.
    D. 1680 km.

13. A journey from Edmonton to Calgary takes 3 hours when travelling at an average speed of 60 miles per hour. How long would the return trip take if the average speed is kept down to 50 miles per hour?

    A. 2.5 hours
    B. 2.6 hours
    C. 3.0 hours
    D. 3.6 hours

14. Five men can build a large pre-fab house in 10 days. How long will it take 15 men, of equal capability, to build an identical house?

    A. 3.0 days
    B. 3.3 days
    C. 15 days
    D. 30 days

15. A Scout group decide to raise money by washing cars. On a trial run they discover that 20 boys can wash 40 cars in 4 hours. How many boys are required to wash 60 cars in 3 hours?

    A. 10
    B. 20
    C. 30
    D. 40

SECTION II

Questions 16 - 18 deal with the following:

Harry, Jim and Sam are friends. Harry runs faster than Jim and Harry runs slower than Sam. Place the correct answer in each case on the answer sheet.

16. Jim runs faster than Sam.

    a) right
    b) wrong
    c) cannot say

17. Sam runs faster than Harry.

    a) right
    b) wrong
    c) cannot say

18. The fastest boy is:

    a) Harry
    b) Jim
    c) Sam

Questions 19 and 20 deal with the following:

Consider X, Y and Z. If o means taller than, faster than, darker than, and x is its opposite, then we may write:

X o Y

X x Z.

Now select the correct answer in each case.

19. Y o X

    a) right
    b) wrong
    c) cannot say

Form B

20. Z x Y

a) right
b) wrong
c) cannot say

Questions 21-30 consist of analogy questions involving both words and numbers. In each question you will find three capitalized words (or numbers) and in brackets, a group of four uncapitalized words lettered a, b, c and d. You are to select from the four uncapitalized words that word which best completes the analogy with the three capitalized words. In each case place your answer on the answer sheet.

For example:

TRIANGLE : SQUARE :: 3 : a) 1
b) 3
c) 3
d) 4

The single colon between words means 'is to' and the double colon means 'as to'. That is, TRIANGLE is to SQUARE as 3 is to ?

Since a triangle is a geometric figure which has three sides and a square is a geometric figure which has four sides, the correct choice is d) 4.

21. HEARSE : CURSE :: WORSE : a) first
b) course
c) furze
d) verse

22. ROCK : SOAP :: GASOLINE : a) dish
b) pill
c) cherry
d) pop

23. 1/3 : 1 :: a) 1 : 6
b) 2
c) 3
d) 4

24. HEADGEAR : CAP :: FRUIT :
a) peach
b) orchard
c) tree
d) fly

25. 17 : 4 ::
a) 49 : 7
b) 50
c) 51
d) 68

26. HERMIT : DRAW :: CRAB :
a) claw
b) scuttle
c) connect
d) bridge

27. 121 : 11 ::
a) 101 : 9
b) 91
c) 81
d) 71

28. 16 : 23 ::
a) 2 : 10
b) 3
c) 4
d) 5

29. CORK : FLOAT :: SUGAR :
a) crystallize
b) dissolve
c) sweeten
d) condense

30. STUDENT : PROFESSOR ::
a) complain : TEACH
b) plan
c) study
d) revel

Name: ______________________

Form B

Class: ______________________

In Questions 31 - 34 put in the correct number in the space provided. Explain the reason for your answer in each case.

31. The next number in the series is

8, 15, 23, ☐

Explanation:

32. Determine the missing number

5	7	4	6
13	17	11	☐

Explanation:

33. The next number in the series is

3, 5, 9, 17, ☐

Explanation:

34. Determine the missing number

2	4	3	5
8	64	27	☐

Explanation:

APPENDIX B

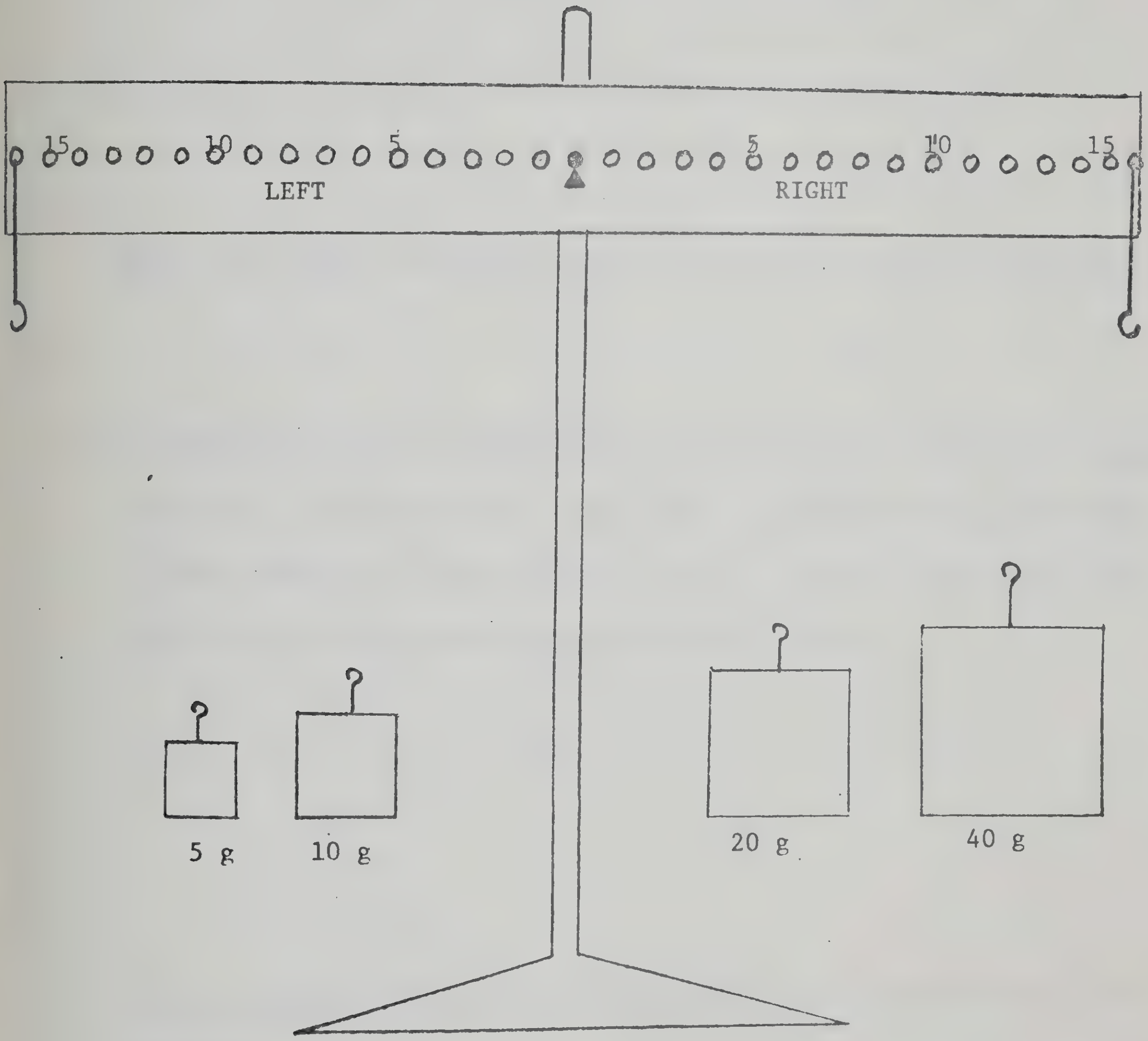
THE PIAGETIAN TASKS (PT)

NAME______________________________

CLASS______________

DATE_______________

This booklet consists of four exercises. IT IS NOT A TEST ! However we would like to see the approach you use in arriving at your solution to each task. It is therefore essential that you show all your work clearly.



The balance shown above contains 16 holes on each side of the crossbar on which can be hung weights of various sizes. Before the addition of any weights the balance remains in a neutral or horizontal position.

Now turn the page and answer the following questions about the balance.

A i) Suppose a 10 gram weight is placed in the end hole (#16) of the left hand side of the balance. What would be the resulting position of the balance ? Show the resulting position by means of a small diagram.

WHY do you think the balance should be in the position you indicated ?

ii) Suppose you wanted to balance the 10 gram weight in the above question by using a 20 gram weight. Where would you place the 20 gram weight? Draw a diagram to illustrate your answer. Indicate the number of the hole in which you would place the weight clearly.

Explain why you placed the 20 g weight in the position shown in the diagram.

B. Consider a 20 gram weight suspended from the midpoint (#8 hole) of the left hand side of the balance. Where would you place a 40 gram weight to restore the balance to a neutral position ? Illustrate by means of a diagram and show the hole number clearly.

Explain why you think the weight should be in the position drawn.

C. Illustrate how you would balance a 20 gram weight placed in the #7 hole of the left hand side of the balance by using only a 10 gram weight.

Explain why you drew the 10 g weight in the above position.

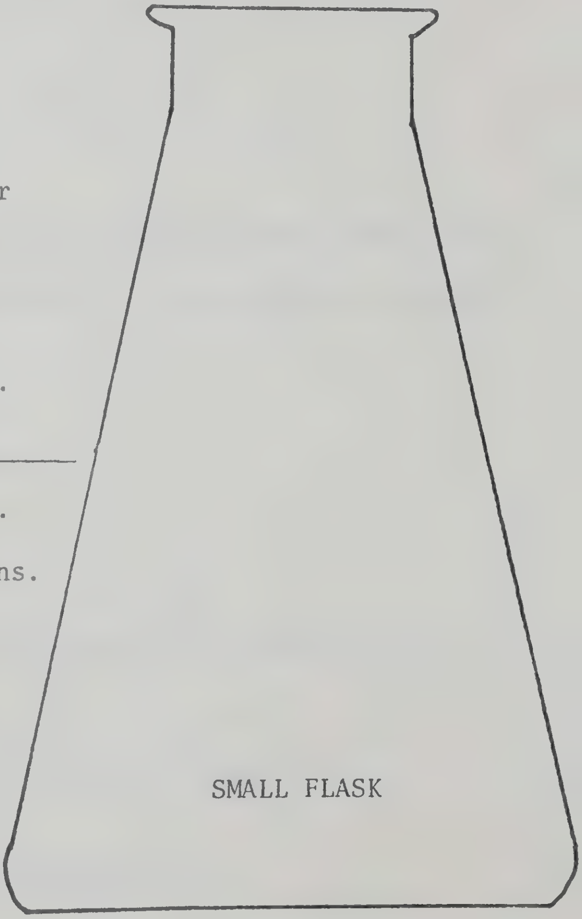
2. RATIO TASK (RT)

The figure drawn below represents a SMALL chemical flask. When measured with large paper clips, the height of the small flask was found to be 4 clips. When a similar LARGE flask (not shown in the diagram) was measured with the same large paper clips, it was found to be 6 clips high.

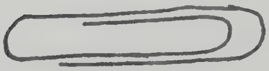
Now please do these things:

1. Measure the height of the small flask on the right using the SMALL paper clips provided. The height is ______ SMALL paper clips.
2. PREDICT the height of the LARGE flask if it were measured with the same small clips. The height of the LARGE flask would be ________
3. EXPLAIN how you arrived at your prediction. You may use diagrams, words, or calculations. Please explain your steps carefully.

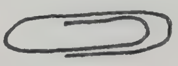
EXPLANATION (Be precise)



large paper clip



small paper clip



3. METRIC PUZZLE (MP)

In preparation for the total metric conversion, the Province of Alberta has begun to change their highway distance road signs to a dual English-Metric system. Shown below is an example of a sign that you might see if you drove towards Calgary.

CALGARY
180 MILES
288 KILOMETRES

Suppose that the Province of Saskatchewan also converts their road signs to the same system. As you drive towards SASKATOON you might see the following sign.

SASKATOON
350 MILES
___ KILOMETRES

Are you able to compute the number to put in the blank shown from the data given on this page ? YES ______ NO _______

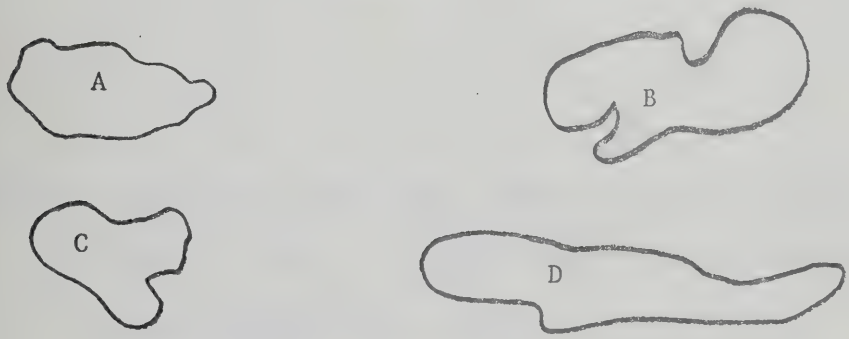
If you can compute the number to put in the blank, please do so.

EXPLAIN IN WORDS HOW YOU CALCULATED YOUR RESULT.

4. ISLANDS PUZZLE (IP)

This puzzle is about Islands A, B, C, and D in the Ocean. People have been travelling among these Islands by boat for many years, but recently an airline started in business. Carefully read the clues about possible plane trips at present. The trips may be direct or include stops and plane changes on an island. When a trip is possible, it can be made in either direction between the islands. You may make notes or marks on the map to help use the clues.

ISLANDS MAP



FIRST CLUE People can go by plane between Islands C and D.

SECOND CLUE People cannot go by plane between Islands A and B.

Use these two clues to answer Question 1. Do not read the next clue yet.

QUESTION 1. Can people go by plane between Island B and D ?

YES ___ NO ___ CANNOT tell from the two clues ____.

Please EXPLAIN your answer.

THIRD CLUE (Do not change your answer to Question 1 now !)

People can go by plane between Island B and D.

Use all three clues to answer Questions 2 and 3.

QUESTION 2. Can people go by plane between Island B and C ?

YES ____ NO ____ CANNOT tell from the three clues ____.

Please EXPLAIN your answer.

QUESTION 3. Can people go by plane between Islands A and C ?

YES ____ NO ____ CANNOT tell from the three clues ____.

Please EXPLAIN your answer.

APPENDIX B

Criteria Used In Performance Assessment On Piagetian Tasks (PT) : Balance Problems (BP), Ratio Task (RT), Metric Puzzle (MP) and Islands Puzzle (IP).

Balance Problems (BP)

Formal Thought (F) At this level the student is able to make the transition from qualitative correspondences in the balance problems to numerical proportions. Students initially discover that a given increase in weight can be compensated by a proportional decrease in the distance of the weight from the central axis. However he also notes the increase in weight can be cancelled by taking away the added weight, by increasing the weight on the opposing side, or by increasing the distance on the opposing side. At the early formal level (F_1), the student begins to conclude that the four variables are interrelated.

At the late formal stage (F_2), the student becomes able to use the notion of a proportionality between weights and distances i.e. W_1 is to W_2 as D_2 is to D_1. Problems (see for example question C in the Balance Problems) which students could not handle with qualitative reasoning can now be resolved using the proportionality relationship.

Concrete Thought (C) Students apply a qualitative scheme for proportions in the form of a system of compensations. Initially students clearly apply the rule for equilibrium by placing equal weights at equal distances from the central axis. Although this qualitative approach is extended to include "the heavier the weight, the closer it must be placed to the middle", there is no evidence available to indicate that the student is utilizing a true proportionality relationship.

Ratio Task (RT) and Metric Puzzle (MP)

Formal Thought (F) In the Ratio Task (RT) each small paper clip corres-

ponds to a certain number of large paper clips, an intermediate quantity not stated in the Task nor asked for. Once this conversion is known, the answer is found by simple calculation. Alternatively, the student might conceptualize the size ratio, another intermediate abstraction, and then reason that this ratio must be invariant with respect to the units of measurement. Similar reasoning is required in the metric puzzle. Often students set up equivalent ratios from the given data to form a proportionality expression in terms of X.

Concrete Thought (C) Since the large flask measures a greater number of large clips than the small flask, students simply add the differences to the measured height of the small flask. Even though the arithmetic difference is not stated or asked for, it is a much more direct measure of the qualitative difference than is the ratio, which comes from making a correspondence between small and large flasks or miles and kilometers. Another approach taken is to simply approximate the ratio between the large and small clips visually, say 2:1. On both cases no consideration is given to available data.

Islands Puzzle (IP)

Formal Thought (F) On Q2, the trip from Island B to Island C is conceptualized as possibly achieved by a change of planes or stop over at Island D. That is, clues about planes routes are not only evaluated in terms of the direct information they provide, but also in terms of possible inferences based on general rules about connections that were stated in the puzzle.

APPENDIX B

On Q3, the formal thinker imagines all possible routes from Island A to Island C in order to bring to bear the information available in the clues. In particular, he must hypothesize that air travel is possible and evaluate this hypothesis for consistency with the data.

Concrete Thought (C) Since the clues do not give the answers to the questions directly, the concrete thinker either cannot tell or selects certain details from the map (e.g. geographical placement, island separation) or postulates properties of each island to explain his ideas (e.g. Island A has no airport). Properties of one island (size, topography) are conceptually simpler to manipulate than the plane routes which represent relationships between islands. This approach also eliminates the need to make use of the rules for combining plane routes.

The following section presents a number of sample student responses to these tasks, categorized according to the above criteria.

APPENDIX B

Sample Student Responses on Balance Problems (BP)

(Question C only)

Student F(1) The 20 g weight is 2x as much as the 10 g weight, 20 g weight is in the 7th hole, 2 x 7 = 14, therefore 10 g weight would be in 14th hole.

Student F(2) The 10 g weight is half as heavy so I moved it twice as far as the 20 g weight.

Student F(3) Because the 20 g weight is twice as much as the 10 g weight and in order for it to balance the 10 g weight must be put in the hole that is 2 times as much as the other.

Student F(4) As 10 is half as much as 20 so it should be twice as far away from the fulcrum.

Student C(1) Because the 10 g is further from the center of the balance. (10 gram weight is shown in hole #13 on right hand side).

Student C(2) (No diagram shown) The bar is not enough for the 10 g weight.

Student C(3) It's a guess. (10 gram weight shown in #1 hole on right hand side)

Student C(4) Can't be done for need hole in between 3 and 4 hole on right side so that the 10 g weight on right side will balance 20 g weight on left side.

Sample Student Responses on Ratio Task (RT)

Student F(1) I divided 4 into 6, got 1.5 and multiplied by six equalling nine.

Student F(2)

small flask		large flask	
large clips	4	large clips	6
small clips	6	small clips	x

$$\frac{4}{6} = \frac{6}{x}\text{ , }36=4x.\ x=9$$

Student F(3) Because the large and small flasks were measured before and it showed that the large was 1.5 times the small in paper clips. The same was done here, 6 x 1.5 = 9.

Student C(1) I estimate there are about 2 small clips to one large so I added on four small clips because I think that is the right size. (ans. 8).

Student C(2) The large flask is about twice the size of the small so double how many clips it took to measure the small flask. (ans. 12).

Student C(3) When the same clips are used the other flask would not vary too much in size. (ans 10).

Student C(4) Because with the big paper clips the ratio is 4:6 so you could use the same ratio to figure it out to be 6:8.

Sample Student Responses to Metric Puzzle (MP)

Student F(1) We have a ratio of 180 miles to 288 km, compared to 350 miles per x km, therefore

$$\frac{180}{288} = \frac{350}{x} \quad , x = 560$$

Student F(2) If 180 miles equals 288 kilometres the 350 miles must equal x km.

$$\frac{180}{288} = \frac{350}{x} \quad , x = 560$$

Student F(3) Divide 180 by 288, ans. 1.6, multiplied amount of miles by 1.6 and got ans.

Student F(4) Using ratios determine relationship between miles-kms.

180:288
350: x cross multiply to get answer.

Student C)1) Well, if 180 miles is 288 kilometres, I added 180 to 180 to get 360 and then added 288 and 288 to get 576, subtracted 10 miles and got 566 kilometres. The reason why I subtracted 10 miles becuse when added 180 + 180 I got 360 which was 10 miles more than I needed.

Student C(2) I doubled the miles and added on 50. (ans. 750).

Student C(3) 288 - 180 = 108, 350 + 108 = 458 km.

Student C(4) I can't complete because I do not know how many kilo in one mile.

APPENDIX B

Sample Student Responses to Island Puzzle (IP)

Student F(1)

Q1. Cannot tell, we do not know if Island B even has an airport.

Q2. Yes, could refuel on Island D then on to C.

Q3. There is no information or clues to how A is to get to C. A cannot go to B to D to get to C because of second clue.

Student F(2)

Q1. Cannot tell, not enough information.

Q2. The plane can go to D to stop and from D to B.

Q3. There is not enough information.

Student F(3)

Q1. Cannot tell, we don't know yet if people can come from D to B or C to A to B.

Q2. Yes, B to D to C.

Q3. Cannot tell, no information has been given for Island A.

Student F(4)

Q1. The diagram does not give enough information.

Q2. Yes, because once they get to D they can get to C.

Q3. Cannot tell if you could go from A - C or A - D because of insufficient data.

Student C(1)

Q1. B and D should be able to if C and D can.

Q2. I have no way of knowing whether the planes can go between Islands B and C from the three clues.

Q3. Yes, because A = B can't so A and C should.

Student C(2)

Q1. Yes, as far as can tell. Because it is a shorter distance.

Q2. No, because the plane can only fly direct between the Islands.

Q3. Yes. because it is a short distance.

Student C(3)

Q1. Yes, B and D both have airports or landing strips.

Q2. No, if people can't go from A to B, then wouldn't it be logical that people can't go from B to C?

Q3. Yes, they can stop over at Island C.

APPENDIX C

NAME ____________________

CLASS ____________________

DATE ____________________

CHEMISTRY 10 (CPT (1)]

COMPOUNDS AND NOMENCLATURE

THIS TEST CONSISTS OF TWO SECTIONS. In the FIRST section which consists of 20 multiple choice place your answer to each question in the ANSWER SPACE PROVIDED.

In the SECOND section which consists of 3 questions you are to place your answer to each question in the space provided on the QUESTION PAPER. SHOW ALL YOUR WORK.

GOOD LUCK!

SECTION I

1. The number of atoms of oxygen represented by one formula unit of aluminum sulphate [$Al_2(SO_4)_3$] is:

   a. 3 c. 7
   b. 4 d. 12

   ____

2. The electron rearrangement occuring when copper and oxygen combine to form the ionic compound, Cu_2O, can best be described as:

   a. each copper atom sharing one electron and each oxygen atom sharing two electrons.
   b. each copper atom sharing two electrons and each oxygen atom sharing one electron.
   c, each copper atom losing one electron and each oxygen atom gaining two electrons.
   d. each copper atom gaining one electron and each oxygen atom losing two electrons.

   ____

3. A molecule of a carbon compound is found to contain two hydrogen atoms per carbon atom. A possible formula for this compound might be:

   a. C_2H_2 c. C_6H_{12}
   b. C_4H_{10} d. C_8H_{18}

   ____

4. An element A combines with another element B to form a compound. If A atoms lose 3 electrons each, and B atoms gain 3 electrons each, the compound has the formula:

   a. A_3B c. A_3B_3
   b. AB_3 d. AB

   ____

5. A metallic ion represented by X^{2+} might have which of the following combinations of sub-atomic particles?

a. 11 electrons + 11 protons
b. 9 electrons + 9 protons
c. 9 electrons + 11 protons
d. 11 electrons + 9 protons

______

6. In the formation of the compound calcium fluoride (CaF_2) the number of electrons exchanged per formula unit would be:

a. 1
b. 2
c. 3
d. 6

______

7. In the formation of ionic bonds which of the following is TRUE? The ratio of electrons lost by the metallic ion to the electrons gained by the non-metallic ions or radical is:

a. always equal to one
b. sometimes equal to one
c. usually greater than one
d. usually less than one

______

8. Elements of group IA (except hydrogen) react with elements of group VIA to form:

a. molecules
b. complex ions
c. ionic solids
d. gaseous compounds

______

9. A sample of aluminum carbonate that contains 10,000 aluminum ions must also contain how many carbonate ions?

a. 10,000
b. 12,000
c. 15,000
d. 30,000

______

10. The type of bond that will most likely form when two atoms combine can best be predicted from each atom's:

a. total number of electrons
b. number of valence electrons
c. nuclear charge
d. atomic mass

______

In Questions 11 - 13 you are required to predict a valence or combining number for the unknown ion or radical given the formula containing a known ion and the unknown ion.

11. The valence or ion charge of X in X_2O_3 would be:

a. 1
b. 2
c. 3
d. 4

______

12. The valence or ion charge of Y in YCL would be:

a. 1
b. 2
c. 3
d. 4

______

13. The valence or ion charge of Z in AlZ would be:

a. 1 c. 3
b. 2 d. 4 __________

14. Unknown R and T ions form ionic compounds with calcium and fluoride ions - SF and CaT. A possible formula for the ionic compound formed between unknown ions R and T might be:

a. RT c. R_2T
b. RT_2 d. R_2T_3 __________

15. Unknown D and E form ionic compounds with potassium and sulfide ions - D_2S and KE. A possible formula for the ionic compound formed between unknown ions D and E might be:

a. DE c. D_2E
b. DE_2 d. D_2E_3 __________

16. The formula unit which shows the respective atoms or ions in the smallest possible whole number ratio is called the simplest formula for that substance. Which of the following represent a simplest formula?

a. C_2H_6 c. N_2O_4
b. H_2O_2 d. SnF_2 __________

17. The correct name for the compound Fe_2S_3 is:

a. diiron trisulfide c. iron (II) sulfide
b. iron (III) sulfide d. ferrous sulfide __________

Use this information to answer questions 18, 19 and 20:

Suppose 200,000 aluminum atoms react with oxygen to form aluminum oxide.

18. The formula for the compound that forms will be:

a. AlO_3 c. Al_2O
b. Al_2O_3 d. AlO __________

19. How many oxygen atoms will combine with the aluminum atoms?

a. 100,000 c. 300,000
b. 200,000 d. 400,000 __________

20. How many electrons in all will be lost by the 200,000 Al atoms and gained by the 0 atoms in this reaction? (Hint - aluminum forms + 3 ions)

    a. 600,000　　c. 300,000

    b. 400,000　　d. 200,000　　__________

21. The correct name for the compound $SnCl_2$ is

    a. tin chloride　　c. stannous (II) chloride

    b. stannous chloride　　d. stannic chloride　　__________

22. The correct name for $HNO_{3(aq)}$ is

    a. Hydrogen nitrate　　c. nitric acid

    b. hydrogen nitrite　　d. hydriodic acid　　__________

23. In the formation of the ionic compound ferric nitride, the total charge per formula unit after the transfer of electrons would be

    a. 0　　c. 2

    b. 1　　d. 3　　__________

24. If calcium reacts with chlorine, the product will be called

    a. calcium dichloride　　c. calcium dichlorine

    b. calcium chlorine　　d. calcium chloride　　__________

25. Which statement is false? Binary compounds

    a. have names ending in 'ide'
    b. contain two kinds of atoms only
    c. are diatomic
    d. may be ionic or molecular　　__________

CHEM 10 - [CPT (1)]

SECTION II

This section consists of 3 questions. Place all your work to each question in the space provided on the question sheet.

Question 1

A. Consider the two gaseous molecules: H_2O (water vapor) and H_2S (hydrogen sulphide). Determine the combining ratio between the number of hydrogen atoms and the non-metallic atom in each molecule.

i. $$\text{Ratio} = \frac{\text{number of hydrogen atoms per molecule of } H_2O}{\text{number of oxygen atoms per molecule of } H_2O} = \underline{\qquad\qquad}$$

ii. $$\text{Ratio} = \frac{\text{number of hydrogen atoms per molecule of } H_2S}{\text{number of sulphur atoms per molecule of } H_2S} = \underline{\qquad\qquad}$$

B. Determine the ratio by mass of the combining atoms in each gas. (atomic mass of H, O, and S are 1, 16 and 32 respectively).

i. $$\text{Ratio} = \frac{\text{mass of hydrogen atom in } H_2O}{\text{mass of oxygen atom in } H_2O} = \underline{\qquad\qquad}$$

ii. $$\text{Ratio} = \frac{\text{mass of hydrogen atom in } H_2S}{\text{mass of sulphur atom in } H_2S} = \underline{\qquad\qquad}$$

C. How do you explain the difference between the reacting ratios by number of atoms and atomic masses in the above calculation. Be specific in your answer.

Question 2

A. Consider the chemical expression: $2H_2O$

a. What does the above represent? Be precise.

b. Determine the combining ratio between hydrogen and oxygen atoms in the above expression.

Question 3

Two students A and B are given unknown samples of a colorless, odorless gas. After analysis both samples are found to contain only the elements carbon and oxygen. Student A maintains that his sample contains 1.33g of oxygen for every grain of carbon. Student B claims his sample contains 2.66g of oxygen per gram of carbon. Can you account for these results? Explain your answer carefully.

	Carbon	Oxygen
Student A	1.00g	1.33g
Student B	1.00g	2.66g

Name: ____________________

APPENDIX C

Class: ____________________

Date: ____________________

CHEMISTRY 10 [CPT (2)]

CHEMICAL REACTIONS

THIS TEST CONSISTS OF TWO SECTIONS. In the FIRST section which consists of 20 multiple choice questions, please place your answer to each question in the ANSWER SPACE PROVIDED.

In the SECOND section which consists of 3 questions you are to place your answer to each question in the space provided on the QUESTION PAPER. SHOW ALL YOUR WORK.

Good Luck!

SECTION I

1. In the reaction:

$$Cl_2 + C_{10}H_{16} = C + HCl \quad \text{(unbalanced)}$$

the ratio of molecules of chlorine Cl_2 reacting with molecules of $C_{10}H_{16}$ is:

a. 1:8   c. 16:1
b. 8:1   d. 8:10   ____________

2. Sulfuric acid + aluminum hydroxide ⟶ water + aluminum sulfate

The balanced equation for the above word equation is:

a. $H_2S + Al(OH)_2 \longrightarrow HOH + AlSO_4$
b. $HSO_4 + AlOH \longrightarrow HOH + AlSO_4$
c. $3H_2SO_4 + 2AlH_3 \longrightarrow 6H_2 + Al_2(SO_4)_3$
d. $3H_2SO_4 + 2Al(OH)_3 \longrightarrow 6HOH + Al_2(SO_4)_3$ ____________

3. Metals lose electrons in order to form more stable outer shells. Sodium with one electron in its outer shell loses this electron to form the sodium ion, Na^+. As a result the ratio of electrons to protons in the Na^+ ion will be:

a. less than one   c. greater than one
b. equal to one   d. same as before   ____________

4. $2NaOH + H_2SO_{4(aq)} \longrightarrow 2HOH + Na_2SO_4$

If 8.00 g of NaOH react with 9.81 g of H_2SO_4 to produce 3.60 g of HOH, then the mass of Na_2SO_4 produced is:

a. 6.21   c. 17.81
b. 14.21   d. 21.41   ____________

5. In a balanced chemical reaction, the ratio of the total number of molecules on the left hand side of the equation compared to the number of molecules on the right hand side is:

a. always less than one
b. always equal to one
c. sometimes equal to one
d. always greater than one
______

6. $\_\_NaOH + \_\_Al(NO_3)_3 \longrightarrow \_\_Al(OH)_3 + \_\_NaNO_3$

Balance the above equation using simplest whole numbers. The coefficient (number in front) for $Al(NO_3)_3$ would be:

a. 1
b. 2
c. 3
d. 4
______

7. In the reaction:

$$N_2 + 2O_2 \longrightarrow N_2O_4$$

it is found that the complete reaction of 28 grams of nitrogen with sufficient oxygen will form 92 grams of the oxide, dinitrogen tetraoxide. The number of grams of nitrogen needed to produce 46 grams of oxide would therefore be:

a. 14
b. 46
c. 56
d. 74
______

8. Which of the following is NOT involved in balancing chemical equations?

a. conservation of atoms
b. conservation of mass
c. conservation of energy
d. conservation of molecules
______

9. Consider the following unbalanced equation:

$$\_\_S_8 + \_\_O_2 \longrightarrow \_\_SO_2$$

When the above equation is balanced, the coefficients from left to right are:

a. $0,\ 8 \longrightarrow 2$
b. $0,\ 8 \longrightarrow 8$
c. $1,\ 8 \longrightarrow 2$
d. $1,\ 8 \longrightarrow 8$
______

10. $4FeS_2 + 11O_2 \longrightarrow 2Fe_2O_3 + 8SO_2$

Which of the statements about the above equation is FALSE?

a. Four formula units of FeS_2 will produce eight molecules of SO_2.

b. Oxygen has 11 atoms per molecule.

c. There are four ions of Fe on the right hand side of the equation.

d. The name for Fe_2O_3 is ferric oxide.
______

11. $C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$

Which of the following statements about the above equation is TRUE?

a. 2 molecules of C_3H_8 will react with 10 molecules of oxygen.
b. 1 molecule of C_3H_8 will produce 2 molecules of products.
c. 1 molecule of C_3H_8 will react with 10 molecules of oxygen.
d. The equation is NOT balanced. __________

12. There is a family of hydrocarbons, some of which have the formulae, C_2H_6, C_3H_8, C_4H_{10} and C_5H_{12}. In this same family the member which has ten carbon atoms per molecule would have the formula:

a. $C_{10}H_{18}$ c. $C_{10}H_{22}$
b. $C_{10}H_{20}$ d. $C_{10}H_{24}$ __________

13. Which of the following members of the oxy-acids of chlorine has the greatest ratio of chlorine to oxygen?

a. $HClO_4$ c. $HClO_2$
b. $HClO_3$ d. $HClO$ __________

14. The product in the reaction between lithium and nitrogen is:

a. LiN_2 c. LiN_3
b. Li_2N d. Li_3N __________

15. __Cu_2S + __$O_2 \longrightarrow Cu_2O$ + __SO_2

The coefficient for oxygen in the above equation would be (use whole numbers only):

a. 1 c. 3
b. 2 d. none of the above __________

16. The reaction represented by the equation, $H_2CO_{3(aq)} \longrightarrow H_2O + CO_2$, is an example of:

a. combustion of hydrocarbon c. decomposition
b. double replacement d. simple composition __________

17. A chemical reaction produced AgBr and $CsNO_3$. The reactants involved in the reaction were:

a. $CsNO_3$ and AgBr c. CsAg and $BrNO_3$
b. CsBr and $AgNO_3$ d. CsBr + NO_2 + Ag __________

18. Which of the following statements about a balanced chemical question is FALSE?

    a. The ratio of mass of reactants to products is always equal to one.
    b. The ratio of atoms of reactants to products is always equal to one.
    c. The ratio of molecules of reactants to products is always equal to one.
    d. The total number of atoms involved in a reaction remains unchanged.

______

19. Atomic masses of elements are rarely whole numbers because:

    a. Methods of atomic mass determination are not very accurate.
    b. It is hard to isolate pure samples of elements.
    c. The number of protons often differs from the number of neutrons.
    d. Most elements consist of different kinds of atoms, called isotopes.

______

20. Suppose a chemistry student incorrectly used the formula, H_4O_2, for water in the equation for the reaction between hydrogen and oxygen to form water. As a result, his balanced equation would show the reacting ratio between hydrogen and oxygen as:

    a. greater than the correct ratio
    b. same as the correct ratio
    c. less than the correct ratio
    d. insufficient information

______

SECTION II

For each question in this section show all your work used in arriving at your answer.

Question 1

Two gaseous elements with symbols A and B are found to have atomic weights of 12 and 8 respectively. Molecule A is found to contain two atoms per molecule while B contains 3 atoms per molecule. When combined, elements A and B form a stable gaseous compound, AB_2.

a. Write a balanced chemical equation for the reaction between A and B.

b. What is the reacting ratio of A and B in terms of:

    i) molecules of A and B?

    ii) moles of A and B?

    iii) molar masses of A and B?

Question 1, con't...

c. How many molecules of B would be required to completely react with 10,000 molecules of A?

Question 2

One student maintains that the correct chemical interpretation of the reaction below is that one atom of A reacts with 4 atoms of B to form one molecule of AB_4. His friend claims that a more accurate statement would be, one mole of A reacts with 4 moles of B to form one mole of AB_4. Are either of these interpretations correct? Discuss your answer.

(equation)	A	+	4B	$\longrightarrow$	AB_4
Student 1	one atom	+	4 atoms	$\longrightarrow$	one molecule
Student 2	one mole	+	4 moles	$\longrightarrow$	one mole

Question 3

From your knolledge of chemistry and balancing equations, suppose you were told of a hydrocarbon with formula C_xH_y, where x and y represent the number of atoms of C and H respectively in the compound. The unbalanced equation for the complete combustion of this hydrocarbon in air is given by:

$$C_xH_y + O_2 \longrightarrow \_\_CO_2 + H_2O$$

a. What would be the coefficient of the carbon dioxide molecule in the balanced equation? (In terms of x)

Question 3, con't...

b. What would be the coefficient of the water molecule in the balanced equation? (In terms of y)

c. Calculate the moles of carbon dioxide to moles of water formed in the reaction.

ratio = ____________

d. Write the complete balanced equation for this reaction.

APPENDIX C

CHEMISTRY 10 [CPT (3)]

THE MOLE

THIS TEST CONSISTS OF TWO SECTIONS. In the FIRST section which consists of 20 multiple choice, place your answer to each question in the ANSWER SHEET PROVIDED.

In the SECOND section which consists of 3 questions, you are to place your answer to each question in the space provided on the QUESTION PAPER. SHOW ALL YOUR WORK.

Good Luck!

SECTION I

1. If $16CO_2$ represents sixteen moles of carbon dioxide molecules then the total number of moles of atoms represented is:

   a. 16 c. 48
   b. 32 d. 64

2. The number of moles in 7.56 g of epsom salts, $MgSO_4$ (molar mass = 120 g) is:

   a. .0630 c. 0.130
   b. 0.110 d. 7.60

3. Given that:

   $$2KOH + H_2SO_4 \longrightarrow K_2SO_3 + 2H_2O$$

   How many moles of H_2SO_4 are required to react with 1 mole of KOH?

   a. 1/2 c. 2
   b. 1 d. 4

4. Given that:

   $$Mg + S \longrightarrow MgS$$

   What mass in grams of Mg would react completely with 32 g (1 mole) of S?

   a. 12 c. 32
   b. 24 d. 56

5. If you predict that 1.20 mol of calcium oxide (lime) should be used in a chemical reaction, then the mass of calcium oxide reacted should be:

   a. 0.0214g c. 56.1g
   b. 46.8g d. 67.3g

6. The number of moles of NaOH (molar mass = 40 g) that would be equal in mass to 2.00 moles of $CaCO_3$ (molar mass = 100 g) is:

a. 2,00
b. 2.50
c. 3.33
d. 5.00

7. The measurement that shows three significant digits is:

a. 305.1 g
b. 0.1059 g
c. 0.006 g
d. 20.4 g

8. The number of moles of NaCl in a two pound (908 g) box of table salt is:

a. 0.0644 mol
b. 15.5 mol
c. 58.5 mol
d. 5.31×10^4 mol

9. The molar mass of sodium sulfate is:

a. 55.1 g
b. 70.0 g
c. 119 g
d. 142 g

10. Planet Y has the same elements as planet earth but a different system of weights and measures. In their system nitrogen atoms have a molar mass of 21 units. In their system helium atoms would have a molar mass of:

a. 2.0 units
b. 4.0 units
c. 6.0 units
d. 8.0 units

11. Assume sulfur was S_4 instead of S_8. 3.00 moles of sulfur would have a mass of:

a. 96.0 g
b. 128 g
c. 256 g
d. 385 g

12. Given that

$$S + O_2 \longrightarrow SO_2$$

What mass in grams of O_2 is required with 1/2 mole of S?

a. 16
b. 24
c. 32
d. 48

13. The mass of 0.25 mole of a compound with the molecular formula AB_3 is 17 g. If the molar mass of element A is 11g/mol, the molar mass of element B, in g/mol, is:

a. 19
b. 28.5
c. 33
d. 57

14. The number of moles of atoms in 1.40 g of copper (molar mass = 63.5 g) is:

a. .0013
b. .0220
c. 0.250
d. 88.9

15. The mass of 6.02×10^{23} molecules of carbon tetrachloride is:

a. 1 mol   c. 6.02×10^{23} g
b. 47.5 g   d. 154 g

16. Given that:

$$\_\,N_2 + \_\,H_2 \longrightarrow \_\,NH_3$$

Calculate how many moles of H_2 would react completely with 1 mole of N_2.

a. 1   c. 3
b. 2   d. 4

17. In the reaction:

$$2A + 3B \longrightarrow 2C + 4D$$

42.0 g of A reacts with 2.0 g of B to produce 20.0 g of C. If the molar mass of C is 10.0 g/mol, the molar mass of D in g/mol is:

a. 4.00   c. 24.0
b. 6.00   d. 40.0

18. One molecule of ethane, C_2H_6, contains:

a. 6 moles of H atoms   c. a total of $8 \times 6.02 \times 10^{23}$ atoms
b. a total of 8 moles of atoms   d. 2 atoms of carbon

19. The atomic wt of znernine is 24.3
The atomic wt of morkur is 14.2
The molar mass of znernine trimorkide would be:

a. 14.2 g/mol   c. 38.5 g/mol
b. 24.3 g/mol   d. 66.9 g/mol

20. In the reaction:

$$C + O_2 \longrightarrow CO_2$$

What mass of O_2 is required to react with 0.25 mol of carbon?

a. 9.0g   c. 64 g
b. 16 g   d. 128 g

Name ____________________

Date ____________________

Class ____________________

CHEMISTRY 10 [CPT (3)]

THE MOLE

SECTION II

Show ALL your work in the SPACE PROVIDED.

1. A student wishes to weigh out samples of three metals (copper, silver and gold) so that all three samples contains the same number of atoms, namely 3.01×10^{23} atoms. How many grams of each metal should be weighed out? Show your calculations.

Cu atomic mass = 63.5	Ag atomic mass = 108	Au atomic mass = 197

2. What mass of iron (atomic mass = 55.8) would contain the same number of atoms that there are in 5.05 g of neon? (atomic mass of Ne = 20.2).

CHEM 10 [CPT (3)]

3. A. The present system of atomic masses uses as its standard that of carbon with its value of exactly 12.000 units. Suppose the atomic mass of carbon was changed to 100 units instead of the present standards. On this new 'metric' scale using carbon 100 as the standard mass, what value would you assign?

   i. the atomic mass of oxygen?

   ii. the atomic mass of hydrogen?

B. Using the newly assigned atomic mass values, calculate the molecular mass for the water molecule:

C. How would the percentage composition of water compare with that based on the carbon 12 system of atomic mass? Explain your answer.

APPENDIX C

CHEMISTRY 10 [CPT (4)]

GRAVIMETRIC STOICHIOMETRY

THIS TEST CONSISTS OF TWO SECTIONS. In the FIRST section which consists of 15 multiple choice questions, place your answer to each question in the ANSWER SHEET PROVIDED.

In the SECOND section which consists of 3 questions you are to place your answer to each question in the space provided on the QUESTION PAPER. SHOW ALL YOUR WORK.

SECTION I

1. If 68 g or 2.0 moles of phosphorus trihydride (PH_3) is decomposed into its elements, the number of moles of hydrogen gas that will be produced is:

   a. 2.0 c. 6.0
   b. 3.0 d. 12

2 Consider the following reaction $CuBr_2 + Ag_2SO_4 \longrightarrow 2AgBr + CuSO_4$

The TRUE statement about the reaction is:

a. k,0 mole of $CuBr_2$ produces 1.0 mole of AgBr.

b. 0.10 mole of $CuBr_2$ reacts with 0.10 moles of Ag_2SO_4.

c. 3,0 moles of Ag_2SO_4 produced 3.0 moles of AgBr.

d. 0.25 moles of AgBr are produced from 0.50 moles of Ag_2SO_4.

3 Consider the following reaction: $N_2 + 3H_2 \longrightarrow 2NH_3$

The MASS of hydrogen in grams which will react with 2.00 moles of nitrogen is:

a. 2.00 c. 6.00
b. 3.00 d. 12.0

4 Consider the following equation: $2Al + Fe_2O_3 \longrightarrow 2Fe + Al_2O_3$

The TRUE statement about the equation is:

a. 2 g Al will react with 1 g of Fe_2O_3.

b. 2 mole Al will produce 2 moles of Fe.

c. 1 g of Fe_2O_3 will produce 2 moles of Fe.

d. 1 mole of Fe_2O_3 will produce 1 g Al_2O_3.

5. Given that:

$$C_2H_6 + \_\_O_2 \longrightarrow \_\_CO_2 + \_\_H_2O \text{ (unbalanced)}$$

The number of moles of O_2 required for the complete combustion of 1.0 mol of C_2H_6 is:

a.	1.0	c.	2.5
b.	2.0	d.	3.5

6. For the reaction $2HCl + Ca(OH)_2 \longrightarrow CaCl_2 + 2H_2O$, the number of moles of water produced when 0.40 mole of $Ca(OH)_2$ is consumed is:

a.	0.10	c.	0.40
b.	0.20	d.	0.80

7. Consider the reaction: $2H_2 + O_2 \longrightarrow 2H_2O$

The mass of water in grams produced when 3.00 moles of oxygen react is:

a.	2.00	c.	108
b.	36.0	d.	204

8. Consider the following reaction: $2H_2 + O_2 \longrightarrow 2H_2O$

A reaction vessel contains 8 g of H_2 and 8 g of O_2. The FALSE statement is:

a.	16 g of H_2O are produced	c.	7 g of H_2 will be unreacted
b.	H_2 is in excess	d.	9 g of products are formed

9. When 32 g of methane, CH_4, burns, water and carbon dioxide are produced. Based on this information the FALSE statement is:

a. 4.0 mol of water are produced
b. 88 g of carbon dioxide are produced
c. 64 g of oxygen are consumed
d. The mass of the reactants equals the mass of the products

10. If you predict that 0.250 mol of sodium carbonate (washing soda) (molar mass = 106 g) should be used in a chemical reaction, then the mass of sodium carbonate in grams used should be:

a.	0.00236	c.	106
b.	26.5	d.	424

11. Sulfur dioxide gas escaping from a natural gas well may react with water to produce an acid which damages the environment.

$$SO_2 + HOH \longrightarrow H_2SO_{3\,(aq)}$$

The mass of sulfur dioxide in grams required to produce 0.50 mol of H_2SO_3 molecules is:

a. 0.50 c. 41
b. 32 d. 64

12. Given the equation $2Na + Cl_2 \longrightarrow 2NaCl$, the number of moles of chlorine gas that react with 0.5 moles of sodium would be:

a. 0.25 c. 1.0
b. 0.50 d. 2.0

13. Consider the reaction: $2Cs + 2HOH \longrightarrow H_2 + 2CsOH$

The TRUE statement about the reaction is:

a. 2 g of Cs will react with 2 g HOH
b. 2 moles of Cs will produce 1 g of H_2
c. 2 g of HOH will produce 2 moles of CsOH
d. 2 Moles of HOH will produce 1 mole of H_2

14. Decomposing 64 g of hydrogen iodide (molar mass = 128 g) into its elements will produce how many moles of hydrogen gas?

a. 0.25 c. 1.0
b. 0.50 d. 32

15. Consider the reaction: $H_2 + Cl_2 \longrightarrow 2HCl$

A reaction vessel contains 71 g of H_2 and 71 g of Cl_2. The FALSE statement about the reaction is:

a. 142 g of HCl are produced c. 69 g of H_2 will be unreacted
b. H_2 is in excess d. 73 g of products are formed

Name____________________

Date____________________

Class____________________

CHEMISTRY 10 [CPT (4)]

GRAVIMETRIC STOICHIOMETRY

SECTION II

This section consists of 3 questions. Be sure to show all your work and calculations in the space provided under each question.

Question 1

For the reaction: $N_2H_4 + 2H_2O_2 \longrightarrow N_2 + 4H_2O$

Calculate the number of moles of water formed when 0.10 moles of N_2H_4 are reacted.

Question 2

Determine the number of grams of carbon produced from the complete decomposition of 176 g of carbon dioxide.

Question 3

Given that: $P_4 + 5O_2 \longrightarrow P_4O_{10}$

A. Calculate how many moles would react completely with 1 mole of O_2.

B. How many grams of P_4 would react completely with 1 mole of O_2?

APPENDIX D

THE CHEMISTRY ACHIEVEMENT TEST (CAT)

EDMONTON PUBLIC SCHOOLS

CHEMISTRY 10 FINAL

January 1975

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GENERAL DIRECTIONS

DIRECTIONS: Fill in the information required on the answer sheet.

Read each item and decide which of the alternatives BEST completes the statement, or answers the question. Locate that question number on the answer sheet and fill in the space that corresponds to the alternative that you have chosen.

Mark your answers according to the instructions

Use ordinary HB pencils only.

Mark ONLY ONE answer for each item. If you wish to change an answer, be sure your original choice has been completely erased.

Do NOT put any marks on this test booklet.

Do NOT bend or fold the answer sheet.

Return BOOKLET and ANSWER SHEET at the end of the period.

1. The alkali metals generally have one electron more than the
   - A. halogens
   - B. inert gases
   - C. alkali earths
   - D. transition elements

Several tests were performed upon an element to determine its chemical and physical properties. The following properties were identified:

1. It fractured upon being hammered.
2. It was a conductor of electricity.
3. It reacted with oxygen to form a compound that is gaseous at room temperature.

2. The element in question is most likely
   - A. a group IIA element
   - B. sulfur
   - C. carbon
   - D. a halogen

Questions 3 and 4 deal with the identification and characteristics of three elements, X, Y and Z. The elements have SUCCESSIVE atomic numbers, ie. each atomic number increases by one in the order given. Element Y is an inert gas.

3. The group of the periodic table in which you would expect to find element X is
   - A. IA
   - B. IIA
   - C. VIIA
   - D. VIIIA

4. Which of the following statements concerning elements X, Y and Z is true?
   - A. Elements X, Y and Z could be in the same chemical family of the periodic table.
   - B. Elements X, Y and Z could be in the same horizontal row (period) of the periodic table.
   - C. Elements X, Y and Z could be those elements with atomic numbers 17, 18 and 19 respectively.
   - D. Both elements X and Z could tend to readily bond with element Y.

---

5. An ion that is most likely from group IA is
   - A. W^{+1}
   - B. X^{+2}
   - C. Y^{-1}
   - D. Z^{-2}

6. A true statement about atoms is that
   - A. most of the volume of an atom is occupied by the nucleus.
   - B. the nucleus contains protons only.
   - C. most of the mass of an atom is centered in the nucleus.
   - D. all atoms are the same size.

7. The description - very dense, good conductor, shiny surface, liquid at room temperature - would fit the element

A. lead
B. mercury
C. iodine
D. aluminum

8. A member of the halogen family is the element

A. bromine
B. zenon
C. francium
D. lithium

9. Which of the following statements about a chemical reaction is FALSE?

A. Atoms or ions are rearranged to produce new substances.
B. Energy is either released or absorbed.
C. Mass is conserved.
D. New atoms are created.

10. Which of the following would NOT necessarily indicate a chemical reaction?

A. $Zn + 2HCl \longrightarrow ZnCl_2 + H_2(g)$
B. Color is changed.
C. Precipitate is formed.
D. $H_2O_{(s)} \longrightarrow H_2O_{(\ell)}$

11. 4.34 g of mercuric oxide decomposes according to the equation, $2HgO \longrightarrow 2Hg + O_2$, to yield 0.32 g of oxygen and a mass of mercury. The mass of mercury produced is

A. 4.02 g
B. 4.18 g
C. 4.66 g
D. 8.36 g

12. ___Cl_2 + ___$C_{10}H_{16}$ $\longrightarrow$ ___C + ___HCl
The coefficient for Cl_2 in the above equation, when it is balanced, is

A. 1
B. 5
C. 8
D. 16

13. Which one of the following does NOT represent a chemical reaction?

A. Chorophyll in green plants manufactures sugar, glucose, from carbon dioxide and water.
B. Grapes ferment to produce wine.
C. Yeast is used to produce carbon dioxide when baking bread.
D. Heat is used to melt solder when soldering water pipes.

14. The mass of product produced by the exact reaction of 6.54 g of zinc metal with 3.21 g of sulfur is

A. 0.200 g
B. 3.33 g
C. 9.75 g
D. 78.0 g

15. The following chemical reactions were performed and some observations were noted:

$CaCl_2 + ZnCO_3 \longrightarrow ZnCl_2 + CaCO_3$ —— a precipitate forms

$HCl + Zn(OH)_2 \longrightarrow HOH + ZnCl_2$ —— no precipitate forms

From the above information alone it is evident that the precipitate is

A. $CaCl_2$
B. $ZnCO_3$
C. $ZnCl_2$
D. $CaCO_3$

16. Some observations for identifying whether a chemical reaction has occurred are:
   1. formation of a precipitate
   2. formation of a gas
   3. color change
   4. heat and/or light is released or absorbed

The observation(s) that indicates that the burning of gasoline in an automobile engine is a chemical reaction is(are)

A. 2 and 4 only
B. 1 only
C. 4 only
D. 1 and 3 only

Use this information to answer questions 17 and 18.

137 g of $Mg(OH)_2$ were reacted according to the equation

$\_\_Mg(OH)_2 + \_\_HBr_{(aq)} \longrightarrow \_\_HOH + \_\_MgBr_2$

17. The number of moles of $Mg(OH)_2$ reacted was

A. 1.54 mol
B. 2.35 mol
C. 3.32 mol
D. 4.57 mol

18. The mass of water produced when 437 g of $MgBr_2$ is produced is

A. 55.4 g
B. 85.7 g
C. 119 g
D. 169 g

---

19. Which one of the following is NOT equivalent to the rest?

A. 6.02×10^{23} O_2 molecules
B. 16.0 g of O_2 molecules
C. 1.00 mol of O_2 molecules
D. Avogadro's number of O_2 molecules

20. Some zinc metal reacted with hydrochloric acid in a laboratory experiment.

initial mass of zinc = 80.0 g
final mass of zinc = 20.0 g

The number of moles of zinc that reacted is

A. 0.306 mol
B. 0.917 mol
C. 1.22 mol
D. 60.0 mol

21. The mass of 0.250 mol of sulfur S_8 , is

A. 32.1 g
B. 257 g
C. 8.02 g
D. 64.2 g

22. To the correct number of significant digits 0.1ℓ is equal to

A. 100 ml
B. 1×10^2 ml
C. 1.00×10^2 ml
D. 10 ml

23. An INCORRECT balancing technique is

A. always zero a balance before use
B. adjust the smallest beam weight first
C. never weigh very hot or cold objects
D. always weigh chemicals in a container

24. A student is to weigh out 0.200 mol of copper powder on a centigram balance. He is weighing into a beaker which has a mass of 156.73 g. He should set his balance to read

A. 169.43 g
B. 12.70 g
C. 63.50 g
D. 144.03 g

25. $\_\_\_Mg + \_\_\_H_3PO_{4(aq)} \longrightarrow \_\_\_H_2 + \_\_\_Mg_3(PO_4)_2$

The number of moles of magnesium metal required to react with 0.900 mol of phosphoric acid, $H_3PO_{4(aq)}$, in a single replacement reaction is

A. 0.300 mol
B. 0.600 mol
C. 0.900 mol
D. 1.35 mol

26. 2.57 g of S_8 are reacted according to the equation, $\_\_\_S_8 + \_\_\_O_2 \longrightarrow \_\_\_SO_2$.

The mass of SO_2 produced is

A. 0.641 g
B. 2.57 g
C. 5.13 g
D. 7.70 g

27. An acid spill or burn should be neutralized immediately with baking soda.

$$H_2SO_{4(aq)} + 2NaHCO_3 \longrightarrow 2HOH + 2CO_2 + Na_2SO_4$$

The mass of sodium bicarbonate required to neutralize 0.0200 mol of sulfuric acid is

A. 0.840 g
B. 1.68 g
C. 1.96 g
D. 3.36 g

28. Slaked lime, $Ca(OH)_2$, reacts with trisodium phosphate or TSP (the commercial name for Na_3PO_4) to produce rock phosphorus and lye.

$$\underline{\ 3\ }\,Ca(OH)_2 + \underline{\ 2\ }\,Na_3PO_4 \longrightarrow \underline{\quad}\,Ca_3(PO_4)_2 + \underline{\quad}\,NaOH$$

The number of moles of trisodium phosphate required to produce 48 g of sodium hydroxide is

A. 0.40 mol
B. 0.60 mol
C. 1.2 mol
D. 3.6 mol

Use the following information to answer questions 29 and 30.

You have 4 test tubes placed in front of you. Each test tube contains 2.34 g of NaCl dissolved in water. $Pb(NO_3)_2$ was added to each test tube to precipitate $PbCl_2$ according to the following table.

test tube 1	0.0100	mol	$Pb(NO_3)_2$	added
test tube 2	0.0200	"	"	"
test tube 3	0.0400	"	"	"
test tube 4	0.0800	"	"	"

29. An exact reaction occurs in test tube number

A. 1
B. 2
C. 3
D. 4

30. The number of moles of precipitate produced in test tube 4 is

A. 0.0100 mol
B. 0.0200 mol
C. 0.0400 mol
D. 0.0800 mol

31. Which one of the following has the greatest mass?

    A. 3.01×10^{23} molecules of nitrogen dioxide, NO_2
    B. 2.00 mol of carbon monoxide, CO
    C. 40.0 g of sodium hydroxide, NaOH
    D. 6.02×10^{23} atoms of zinc, Zn

32. The number of moles in 20.3 g of iron (III) chloride, $FeCl_3$, is

    A. 0.125 mol
    B. 0.500 mol
    C. 4.00 mol
    D. 8.00 mol

33. If 0.250 mol of iron are required for an experiment, then the mass of iron required is

    A. 0.250 g
    B. 1.40 g
    C. 14.0 g
    D. 55.8 g

34. The compound M_2X_3 has a molar mass of 160 grams per mole. If element X is oxygen, then element M is most likely

    A. Al
    B. Ga
    C. Fe
    D. Ni

35. Which of the following represents the type of reading obtained from a centigram balance?

    A. 14.6 g
    B. 124 g
    C. 13.47 g
    D. 0.946 g

36. Which one of the following units does NOT belong with the others?

    A. mole
    B. dozen
    C. gram
    D. pair

37. If Avogadro's number was 3.01×10^{23}, then the molar mass of oxygen atoms would be

    A. 4.00 g/mol
    B. 8.00 g/mol
    C. 16.0 g/mol
    D. 32.0 g/mol

38. Aluminum, Al, reacts with hydrochloric acid, $HCl_{(aq)}$, to form hydrogen gas, H_2, and aluminum chloride, $AlCl_3$. If 5.0 mol of aluminum react, the number of moles of hydrogen gas produced is

A. 2.0 mol
B. 3.0 mol
C. 5.0 mol
D. 7.5 mol

39. In a chemical reaction, potassium metal reacts with chlorine gas to produce potassium chloride, KCl.

The mass of potassium, K, required to react with 0.60 mol of chlorine, Cl_2, is

A. 23 g
B. 43 g
C. 47 g
D. 94 g

40. Mortar may react with hydrochloric (muriatic) acid by the following reaction:

$$\_\_\_Ca(OH)_2 + \_\_\_HCl_{(aq)} \longrightarrow \underline{\;2\;}HOH + \_\_\_CaCl_2$$

The mass of calcium hydroxide required to react with 0.800 mol of hydrochloric acid is

A. 0.400 g
B. 28.4 g
C. 29.6 g
D. 119 g

41. 7.81 g of Na_2S is reacted with $AlPO_4$ according to the following unbalanced chemical equation: $\_\_\_AlPO_4 + \_\_\_Na_2S \longrightarrow \_\_\_Al_2S_3 + \_\_\_Na_3PO_4$

The number of moles of $AlPO_4$ required for a complete reaction is

A. 0.0667 mol
B. 0.100 mol
C. 0.150 mol
D. 0.206 mol

Use the following data to answer questions 42 and 43.
The following balanced equation represents a chemical reaction observed in a lab.

$$Cu + 2AgCH_3COO \text{ ——— } 2Ag + Cu(CH_3COO)_2$$

The data collected was

initial mass of Cu	1.76 g
final mass of Cu	1.12 g
mass of filter paper	0.91 g
mass of filter paper plus silver	3.21 g
mass of beaker	97.24 g
mass of beaker plus $Cu(CH_3COO)_2$	98.89 g

42. A FALSE statement concerning the above reaction is

A. All of the silver acetate reacts.
B. Cupric oxide should be removed from the copper wire before beginning.
C. The final solution is clear blue in color.
D. When filtering the products, silver is in the filtrate.

43. The number of moles of copper reacted is

A. 0.010 mol
B. 0.018 mol
C. 0.028 mol
D. 0.045 mol

44. Chemical bonding in which it is assumed that electrons are "transferred" from one atom to another is termed

A. covalent
B. ionic
C. molecular
D. binary

45. The correct name for $Pb_3(PO_4)_2$ would be

A. trilead diphosphate
B. plumbic phosphate
C. lead (II) phosphate
D. lead (III) phosphate

46. A sample of iron (II) carbonate that contains 4,000 iron (II) ions must also contain how many oxygen atoms?

A. 2,000
B. 4,000
C. 8,000
D. 12,000

47. The element which naturally exists as diatomic molecules is

A. bromine
B. phosphorus
C. carbon
D. gold

48. The common name for carbon tetrahydride is

A. methane
B. ammonia
C. carbon hydride
D. carbonic acid

49. The most typically molecular compound represented below is

A. SrS
B. Mg_3N_2
C. ZnO
D. OF_2

50. The complete combustion of a hydrocarbon yields

A. carbon and hydrogen
B. carbon and water vapor
C. carbon monoxide and water vapor
D. carbon dioxide and water vapor

51. The chlorine used to purify your drinking water was made possible by electrolyzing molten NaCl to produce liquid sodium and gaseous chlorine. The balanced equation for this reaction is

A. $2NaCl \longrightarrow 2Na + Cl_2$
B. $NaCl \longrightarrow Na + Cl$
C. $2NaCl \longrightarrow Na_2 + Cl_2$
D. $NaCl \longrightarrow Na^+ + Cl^-$

52. Which of the following is an example of a single replacement reaction?

A. $NaOH + HCl \longrightarrow NaCl + HOH$
B. $Sn + FeSO_4 \longrightarrow Fe + SnSO_4$
C. $2NO_2 \longrightarrow N_2 + 2O_2$
D. $H_2 + I_2 \longrightarrow 2HI$

53. Potassium hydroxide and barium chloride react to produce barium hydroxide and potassium chloride. The balanced equation for this reaction is

A. $KOH + BaCl_2 \longrightarrow Ba(OH)_2 + KCl$
B. $K(OH)_2 + 2BaCl_2 \longrightarrow 2Ba(OH)_2 + KCl$
C. $KOH + Ba_2Cl \longrightarrow Ba_2(OH)_2 + KCl$
D. $2KOH + BaCl_2 \longrightarrow Ba(OH)_2 + 2KCl$

54. Sulfuric acid + aluminum hydroxide ⟶ water + aluminum sulfate
The balanced equation for the above word equation has coefficients of

A. $1 + 1 \longrightarrow 1 + 1$
B. $1 + 2 \longrightarrow 3 + 1$
C. $3 + 2 \longrightarrow 3 + 1$
D. $3 + 2 \longrightarrow 6 + 1$

55. Which of the following statements is FALSE concerning tests used to distinguish among ammonia, hydrogen, carbon dioxide, and oxygen gases?

A. Ammonia gas can be identified by its odour.
B. Hydrogen gas can be identified by lighting it.
C. Carbon dioxide gas can be identified by condensing it on the side of a cold beaker of water.
D. Oxygen gas can be identified by inserting a glowing splint into the gas.

56. The correct name for the compound $SnCl_2$ is

A. tin dichloride
B. tin(II) chloride
C. stannous (II) chloride
D. Stannic chloride

Use the following information to answer questions 57 and 58.
Potassium, calcium, oxygen and fluorine were placed in an evacuated container which was then sealed. Chemical reactions were initiated and observed to have occurred.

57. The correct formula and corresponding correct name of a possible ionic compound that may have formed is

A. KF - potassium fluoride
B. Ca_2O - calcium oxide
C. OF_2 - oxygen difluoride
D. K_2O - dipotassium oxide

58. The correct formula and corresponding correct name of a possible molecular compound that may have formed is

A. K_2O - potassium oxide
B. CaO - calcium oxide
C. OF_2 - oxygen difluoride
D. CaF_2 - calcium fluoride

59. The following table gives some of the characteristics of three different compounds designated A, B, and C.

Compound	Phase at Room Temp.	Crystalline Nature	Solubility in H_2O	Electrical Conductivity of Pure Substance	Electrical Conductivity of Aqueous Solution
A	solid	crystalline	soluble	nonconductor	conductor
B	liquid	---	soluble	nonconductor	conductor
C	gas	---	low solubility	nonconductor	nonconductor

The most likely ionic compound(s) is/are

A. A
B. B
C. C
D. both A and B

60. An element X combines with another element Y to form an ionic compound. If X atoms lose 2 electrons each, and Y atoms gain 1 electron each, the ratio of X ions to Y ions in the compound is

A. 0 to 2
B. 2 to 0
C. 1 to 2
D. 2 to 1

APPENDIX E

TABLE XX

Test Scores for the Main Study Sample

N=168

ID	Sex	GPT A	GPT B	CAT	CPT 1	CPT 2	CPT 3	CPT 4	CPT T	BP	RT	MP	IP	PT
1	F	25	26	17	11	13	11	10	45	1	1	0	0	T
2	F	23	20	17	8	9	12	5	34	1	0	0	0	C
3	F	19	22	18	16	14	12	10	52	1	0	0	0	C
4	M	21	13	18	8	6	9	6	29	0	0	0	0	C
5	F	19	16	19	16	9	8	6	39	0	0	0	1	C
6	F	22	21	20	14	9	18	10	51	0	0	0	0	C
7	F	22	19	20	11	9	4	6	30	0	0	0	0	C
8	F	27	22	20	10	11	8	3	32	1	1	0	0	T
9	F	18	21	21	17	12	11	7	47	1	0	0	0	C
10	M	20	21	21	17	9	9	6	41	0	0	0	0	C
11	M	28	24	22	13	15	12	8	48	1	0	1	1	F1
12	F	24	20	22	15	11	12	6	44	0	0	0	1	C
13	M	17	15	22	10	8	6	6	30	0	1	0	0	C
14	F	22	24	22	16	14	9	6	45	1	0	0	0	C
15	F	23	22	23	10	10	7	1	28	1	1	0	0	T
16	M	19	21	23	10	8	6	4	28	0	1	1	0	T
17	F	14	22	23	14	10	11	8	43	0	0	0	0	C
18	M	21	13	24	14	10	12	7	43	1	0	1	0	T
19	F	26	23	24	10	11	11	7	39	1	1	1	0	F1
20	F	25	18	24	7	8	8	3	26	1	0	0	1	T
21	F	23	11	24	8	9	10	9	36	0	0	0	1	C
22	F	13	19	25	13	6	6	4	29	0	1	0	0	C
23	F	19	21	25	13	4	7	4	28	0	0	0	0	C
24	M	19	18	25	11	10	9	9	39	0	0	0	0	C
25	M	26	21	25	17	11	6	10	54	1	1	1	1	F2
26	F	22	19	25	15	12	10	7	44	1	1	0	0	T
27	M	27	21	25	14	11	9	4	38	1	1	1	1	F2
28	M	19	17	25	17	8	8	7	40	1	1	0	0	T
29	M	25	25	26	9	5	8	3	25	0	0	0	0	C
30	M	23	21	27	10	10	12	4	36	0	0	0	0	C
31	F	22	23	27	9	9	8	6	32	0	0	0	0	C
32	M	19	22	27	12	15	10	6	43	1	0	0	1	T
33	M	21	21	27	15	9	13	7	44	1	0	1	1	F1
34	F	21	15	27	15	11	10	7	43	1	0	0	0	C
35	M	25	19	27	8	11	12	10	41	1	1	0	0	T
36	F	23	22	27	16	14	12	5	47	1	0	0	0	C
37	M	24	13	28	14	9	13	6	42	0	0	0	0	C
38	M	24	20	28	12	9	12	8	41	1	1	0	1	F1
39	M	21	20	28	13	11	16	8	48	1	1	1	0	F1
40	M	22	24	29	15	14	12	12	53	1	1	1	1	F2
41	M	28	23	29	15	10	9	12	46	0	1	0	1	T
42	M	26	22	29	9	8	15	7	39	1	0	0	1	T
43	F	20	19	29	17	11	13	8	49	0	1	0	1	T

APPENDIX E

TABLE XX (Continued)

ID	Sex	GPT A	GPT B	CAT	CPT 1	CPT 2	CPT 3	CPT 4	CPT T	BP	RT	MP	IP	PT
44	M	16	25	29	14	10	14	3	41	1	1	0	0	T
45	F	21	21	29	17	13	10	10	50	1	0	0	0	C
46	M	26	22	29	18	12	11	9	50	0	0	0	0	C
47	F	23	19	29	8	10	10	7	35	0	0	0	0	C
48	M	26	22	30	19	11	17	10	57	1	1	1	1	F2
49	F	25	22	30	19	14	11	11	55	1	1	0	1	F1
50	F	26	26	30	18	11	9	8	46	0	0	0	0	C
51	M	29	11	30	20	13	15	4	52	1	1	1	0	F1
52	F	24	21	30	18	14	8	10	50	1	1	0	0	T
53	M	19	19	30	10	9	10	12	41	1	0	0	1	T
54	F	24	27	31	14	12	16	7	49	0	1	0	0	C
55	M	14	18	31	10	8	8	5	31	0	0	0	0	C
56	F	24	21	31	12	13	12	8	45	0	1	1	0	T
57	M	21	16	31	16	8	6	1	21	1	0	0	0	C
58	F	16	21	32	18	14	11	10	53	1	0	1	0	T
59	F	20	28	32	17	14	13	8	52	1	1	1	0	F1
60	F	18	19	32	13	9	13	6	41	1	0	0	0	C
61	M	24	23	32	16	14	11	5	46	1	0	0	1	T
62	F	20	17	32	18	13	7	12	50	1	0	0	0	C
63	N	24	24	32	13	10	12	7	42	1	1	0	0	T
64	M	28	12	32	18	14	18	5	55	1	1	1	0	F1
65	F	24	21	32	15	12	7	11	45	0	0	0	0	C
66	F	23	22	33	18	15	18	9	60	1	1	0	1	F1
67	F	27	17	33	18	9	16	10	53	0	1	1	1	F1
68	F	27	23	33	12	13	17	10	52	1	1	0	1	F1
69	F	28	22	34	22	12	12	7	53	1	1	0	0	T
70	F	20	21	34	11	10	12	6	39	0	1	0	0	C
71	F	29	23	34	15	13	14	7	49	1	1	1	0	F1
72	M	22	24	34	15	12	10	8	45	0	0	1	0	C
73	M	21	17	34	11	8	2	8	29	1	1	1	1	F2
74	M	20	20	34	19	14	15	11	59	1	0	0	1	T
75	M	21	26	34	21	15	14	9	59	1	1	1	1	F2
76	F	10	16	35	15	15	13	10	53	0	0	0	0	C
77	M	28	24	35	19	16	15	9	59	1	1	0	1	F1
78	F	26	20	35	18	12	14	8	52	1	0	0	0	C
79	F	24	17	35	10	11	13	8	42	1	0	0	1	T
80	F	19	20	35	15	9	9	8	41	1	0	0	0	C
81	M	22	20	36	17	11	12	9	49	1	0	0	0	C
82	F	24	18	36	20	15	16	12	63	1	1	0	1	F1
83	M	21	18	36	19	12	14	10	55	1	0	0	0	C
84	F	21	21	36	13	10	10	8	41	1	1	0	1	F1
85	F	25	24	37	18	12	16	12	58	0	0	1	0	C
86	F	22	19	37	16	11	11	9	47	1	1	0	1	F1
87	F	23	19	37	18	12	9	9	48	0	1	1	1	F1
88	M	8	11	37	11	10	12	11	44	1	0	0	0	C
89	M	27	31	38	17	15	15	10	57	1	1	1	1	F2

APPENDIX E

TABLE XX (Continued)

ID	Sex	GPT A	GPT A	CAT	CPT 1	CPT 2	CPT 3	CPT 4	CPT T	BP	RT	MP	IP	PT
90	M	25	25	38	17	14	15	10	56	1	1	0	1	F1
91	M	27	27	38	21	17	11	6	55	1	1	0	1	F1
92	M	24	30	38	12	12	17	3	44	1	1	0	1	F1
93	M	12	19	38	15	12	9	9	45	0	1	0	0	C
94	F	25	22	38	10	11	12	5	38	1	0	1	0	T
95	M	26	24	38	20	13	14	13	60	1	1	1	0	F1
96	M	26	26	39	13	13	10	8	44	1	0	0	1	T
97	M	23	19	39	19	14	16	10	59	1	0	0	1	T
98	M	24	26	39	14	14	15	12	55	1	0	0	1	T
99	F	25	25	39	16	13	9	8	46	0	0	1	0	C
100	F	23	25	40	22	15	13	9	59	0	1	0	0	C
101	M	23	30	40	17	12	16	9	54	1	1	1	1	F2
102	F	29	22	40	18	12	9	9	48	0	0	0	0	C
103	F	22	20	40	13	12	14	4	43	0	0	0	1	C
104	F	24	21	41	13	14	14	14	55	0	1	1	0	T
105	F	28	23	41	17	12	11	13	53	0	1	0	0	C
106	M	25	23	42	21	12	12	11	56	1	1	1	0	F1
107	F	26	25	42	21	15	13	13	62	1	1	0	1	F1
108	M	29	26	42	14	13	16	14	57	1	1	1	1	F2
109	M	26	22	42	19	13	15	11	58	0	0	0	0	C
110	M	20	16	42	10	15	9	7	41	0	0	1	1	T
111	M	27	26	42	17	14	12	9	52	1	1	1	0	F1
112	M	25	25	43	15	8	18	9	50	1	1	0	1	F1
113	M	26	27	43	15	14	16	8	53	1	0	0	1	T
114	F	27	27	43	19	13	17	13	72	1	1	1	1	F2
115	F	23	24	43	14	10	8	8	40	0	0	0	0	C
116	M	25	22	43	15	12	14	10	51	1	1	1	0	F1
117	M	23	11	44	19	15	15	11	60	1	1	1	0	F1
118	M	28	21	44	19	14	17	13	63	1	1	0	0	T
119	M	26	23	44	23	k6	k7	6	62	1	1	1	1	F2
120	M	26	22	44	14	15	16	11	56	1	1	1	1	F2
121	M	27	22	44	14	14	14	11	53	1	1	1	0	F1
122	M	27	26	45	17	12	13	6	48	1	0	1	1	F1
123	M	22	22	45	12	13	15	10	50	1	0	0	0	C
124	F	26	20	45	21	15	18	11	65	1	1	1	0	F1
125	F	28	29	45	21	14	18	15	68	0	1	0	1	T
126	F	26	30	45	20	14	20	15	79	0	1	1	1	F1
127	M	28	20	45	22	18	17	13	70	1	1	0	1	F1
128	M	27	33	46	19	13	18	11	61	1	1	1	1	F2
129	F	19	17	46	18	15	14	13	60	1	1	0	0	T
130	M	27	21	46	21	15	15	9	60	1	1	1	1	F2
131	M	29	29	46	17	17	18	11	63	1	1	1	1	F2
132	M	28	28	46	20	19	16	11	66	1	1	1	1	F2

APPENDIX E

TABLE XX (Continued)

ID	Sex	GPT A	GPT B	CAT	CPT 1	CPT 2	CPT 3	CPT 4	CPT T	BP	RT	MP	IP	PT
133	M	23	25	46	18	13	16	8	55	0	1	0	0	C
134	M	28	22	46	16	16	18	14	64	0	0	1	1	T
135	M	26	22	47	20	18	18	11	67	1	1	1	1	F2
136	M	29	21	47	19	15	19	14	67	1	1	1	1	F2
137	F	28	25	47	23	12	13	11	59	1	0	1	0	T
138	F	28	27	47	21	14	19	12	66	1	1	1	1	F2
139	F	21	19	42	20	13	20	11	64	1	1	0	1	F1
140	F	28	27	47	19	19	15	12	60	1	1	1	1	F2
141	M	27	28	48	16	15	13	12	56	0	0	1	0	C
142	M	25	12	48	20	15	16	13	64	1	1	1	1	F2
143	M	26	25	48	23	15	18	9	66	1	0	1	0	T
144	M	30	25	48	15	15	18	14	62	1	1	1	1	F2
145	F	27	28	48	22	17	20	14	73	1	1	1	1	F2
146	F	27	22	49	20	12	17	10	59	0	1	0	1	T
147	M	25	24	49	19	15	18	8	60	1	0	1	1	F1
148	M	31	30	49	23	18	19	15	75	1	1	1	0	F1
149	F	22	15	49	23	13	10	14	60	0	0	1	0	C
150	M	29	28	50	18	14	19	11	62	0	1	1	0	T
151	F	25	28	50	19	16	18	11	64	1	1	0	0	T
152	F	32	29	50	15	16	16	12	59	1	1	1	1	F2
153	M	20	21	51	22	17	13	12	64	1	1	1	1	F2
154	M	26	31	51	22	19	20	15	76	1	1	1	1	F2
155	F	29	28	51	15	14	17	13	59	1	0	0	0	C
156	M	26	19	51	24	18	18	12	72	1	1	1	1	F2
157	M	29	32	51	24	16	18	14	72	1	1	1	1	F2
158	M	26	24	51	20	18	18	14	70	1	1	1	1	F2
159	F	26	21	51	18	14	17	14	63	0	1	0	1	T
160	M	25	26	51	22	15	14	10	61	1	1	1	1	F2
161	M	31	27	52	20	20	20	14	74	1	1	1	1	F2
162	F	23	25	53	20	19	18	14	71	1	1	1	0	F1
163	F	30	25	53	27	15	17	12	65	1	1	1	1	F2
164	F	28	28	54	24	17	16	13	70	1	1	1	1	F2
165	F	30	25	54	20	16	16	12	64	1	1	1	0	F1
166	F	25	24	55	20	18	17	11	66	1	1	1	1	F2
167	M	23	24	56	22	17	18	14	71	1	1	1	1	F2
168	M	31	31	58	24	20	19	15	78	1	1	1	1	F2

APPENDIX F

LEGEND

X refers to dummy items

C refers to conversion type items

R refers to ratio type items

D refers to direct proportionality type items

I refers to indirect proportionality type items

V.R. refers to verbal reasoning type items

V.A refers to verbal analogy type items

Difficulty Index refers to the percentage of students selecting the correct response.

APPENDIX F

TABLE XXI

Test Statistics of the GPT (Form A)

Test Mean = 23.9

Test Variance = 16.2

KR-20 Reliability = 0.69

Item	Type	Keyed Answer	Difficulty Index	Biserial Correlation
1	X	C	.76	.31
2	X	B	.85	.45
3	X	A	.88	.52
4	C	A	.86	.39
5	C	B	.85	.43
6	R	D	.57	.55
7	R	C	.78	.52
8	D	B	.69	.54
9	D	B	.78	.55
10	D	A	.83	.42
11	D	C	.85	.53
12	I	B	.88	.64
13	I	B	.81	.55
14	I	A	.27	.34
15	D+I	B	.47	.23
16	V.R	B	.87	.64
17	V.R	A	.93	.65
18	V.R	C	.95	.72
19	V.R	B	.81	.66
20	V.R	B	.45	.39
21	V.A	D	.78	.41
22	V.A	B	.55	.29
23	V.A	A	.31	.05
24	V.A	C	.88	.73
25	V.A	B	.52	.46
26	V.A	C	.76	.51
27	V.A	C	.92	.83
28	V.A	B	.82	.65
29	V.A	A	.69	.39
30	V.A	C	.51	.61

APPENDIX F

TABLE XXII

Test Statistics of the GPT (Form B)

Test Mean = 22.2

Test Variance = 17.5

KR-20 Reliability = 0.74

Item Number	Type	Keyed Answer	Difficulty Index	Biserial Correlation
1	X	B	.72	.10
2	X	B	.88	.21
3	X	A	.87	.14
4	C	D	.98	.14
5	C	A	.95	.33
6	R	A	.79	.31
7	R	A	.67	.45
8	D	B	.90	.28
9	D	B	.66	.55
10	D	D	.54	.37
11	D	B	.84	.47
12	I	B	.90	.34
13	I	D	.76	.27
14	I	B	.62	.24
15	D+I	D	.44	.32
16	V.R	B	.90	.41
17	V.R	A	.96	.33
18	V.R	C	.92	.49
19	V.R	B	.83	.49
20	V.R	B	.65	.25
21	V.A	D	.72	.33
22	V.A	D	.63	.29
23	V.A	B	.54	.53
24	V.A	A	.77	.35
25	V.A	B	.41	.50
26	V.A	D	.24	.17
27	V.A	C	.69	.58
28	V.A	B	.51	.31
29	V.A	B	.80	.37
30	V.A.	C	.76	.43

APPENDIX F

TABLE XXIII

Test Statistics of the CPT (1)

Test Mean = 15.2

Test Variance = 16.6

KR-20 Reliability = 0.70

Item Number	Proportionality Type	Keyed Answer	Difficulty Index	Biserial Correlation
1	C	D	.77	.56
2	X	C	.34	.44
3	R	C	.85	.51
4	R	D	.67	.45
5	R	C	.58	.42
6	X	B	.72	.25
7	R	A	.42	.28
8	X	C	.44	.46
9	P	C	.36	.60
10	X	B	.56	.17
11	R	C	.79	.72
12	R	A	.91	.43
13	R	C	.64	.63
14	R	C	.58	.62
15	R	A	.65	.76
16	R	D	.82	.41
17	X	B	.75	.66
18	R	B	.86	.70
19	P	C	.60	.67
20	P	A	.52	.57
21	X	B	.79	.70
22	X	C	.84	.48
23	X	A	.64	.58
24	X	D	.61	.34
25	X	C	.40	.36

C=Conversion, R=Ratio, P=proportionality, X=not applicable

APPENDIX F

TABLE XXIV

Test Statistics of the CPT (2)

Test Mean - 12.4

Test Variance = 9.8

KR-20 Reliability = 0.61

Item Number	Proportionality Type	Keyed Answer	Difficulty Index	Biserial Correlation
1	R	B	.62	.47
2	X	D	.81	.63
3	R	A	.70	.33
4	C	B	.82	.50
5	P	C	.21	.38
6	R	A	.88	.48
7	P	A	.73	.62
8	X	D	.37	.44
9	R	D	.94	.14
10	X	B	.56	.50
11	X	A	.29	.58
12	R	C	.70	.53
13	R	D	.47	.44
14	X	D	.81	.65
15	R	C	.56	.42
16	X	C	.67	.35
17	X	B	.86	.63
18	X	C	.39	.55
19	X	D	.46	.48
20	R	B	.52	.44

C=Conversion, R=Ratio, P=Proportionality, X=not applicable

APPENDIX F

TABLE XXV

Test Statistics of the CPT (3)

Test Mean = 12.7

Test Variance = 18.6

KR-20 Reliability = 0.77

Item Number	Proportionality Type	Keyed Answer	Difficulty Index	Biserial Correlation
1	C	C	.66	.71
2	C	A	.85	.83
3	R	A	.65	.65
4	P	B	.67	.69
5	C	D	.61	.56
6	P	D	.46	.54
7	X	D	.86	.59
8	C	B	.73	.76
9	X	D	.55	.54
10	P	C	.69	.67
11	C	D	.62	.54
12	P	A	.80	.66
13	P	A	.34	.51
14	C	B	.76	.55
15	C	D	.61	.53
16	R	C	.72	.69
17	P	B	.37	.53
18	R	D	.47	.58
19	C	D	.61	.65
20	P	A	.72	.74

C=Conversion, R=Ratio, P=Proportionality, X=not applicable

APPENDIX F

TABLE XXVI

Test Statistics of the CPT (4)

Test Mean = 9.1

Test Variance = 10.3

KR-20 Reliability = .70

Item Number	Proportionality Type	Keyed Answer	Difficulty Index	Biserial Correlation
1	P	B	.65	.57
2	R	B	.70	.59
3	P	D	.56	.57
4	R	B	.66	.74
5	R	D	.71	.47
6	R	D	.81	.60
7	C	C	.77	.72
8	P	A	.34	.45
9	P	C	.26	.53
10	C	B	.82	.62
11	P	B	.62	.71
12	R	A	.75	.83
13	R	D	.69	.66
14	P	A	.41	.65
15	P	A	.34	.62

C = Conversion R=Ratio, P=Proportionality

APPENDIX F

TABLE XXVII

Test Statistics of the CAT

Test Mean = 36.7

Test Variance = 98.0

KR-20 Reliability = .87

Item	Keyed Answer	Difficulty Index	Biserial Correlation	Item	Keyed Answer	Difficulty Index	Biserial Correlation
1	B	.55	.47	31	D	.55	.40
2	C	.38	.30	32	A	.82	.63
3	C	.74	.48	33	C	.79	.58
4	C	.69	.59	34	C	.66	.34
5	A	.91	.44	35	C	.61	.32
6	C	.74	.29	36	C	.46	.46
7	B	.95	.21	37	B	.71	.35
8	A	.85	.54	38	D	.58	.67
9	D	.67	.65	39	C	.60	.55
10	D	.82	.35	40	C	.61	.57
11	A	.90	.49	41	A	.47	.61
12	C	.94	.61	42	D	.18	.24
13	D	.65	.52	43	A	.55	.65
14	C	.89	.37	44	B	.62	.53
15	D	.78	.39	45	C	.63	.36
16	A	.82	.62	46	D	.44	.57
17	B	.76	.57	47	A	.63	.66
18	B	.48	.45	48	A	.76	.46
19	B	.70	.36	49	D	.35	.53
20	B	.61	.69	50	D	.85	.62
21	D	.75	.37	51	A	.78	.69
22	B	.39	.43	52	B	.78	.76
23	B	.78	.23	53	D	.70	.46
24	A	.70	.58	54	D	.52	.69
25	D	.66	.61	55	C	.54	.32
26	C	.63	.39	56	B	.65	.42
27	D	.57	.71	57	A	.60	.32
28	A	.49	.48	58	C	.45	.59
29	B	.38	.27	59	A	.25	.07
30	B	.16	.40	60	C	.46	.51

APPENDIX G

ALCHEM

Alberta Chemistry Project Materials

Chemistry 10

1975

Frank Jenkins
George Klimiuk
Dean Hunt
Dick Tompkins

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FOREWORD

The materials contained in this package were written to meet the needs of students in Alberta where a large majority of students take chemistry in high school. An attempt has been made to keep a high level of chemistry content and yet to make the chemistry easier to learn. The latter is achieved by providing single concept labs, experience oriented labs, demonstrations written into the materials, worksheets for drill, and film notes. A reinforcing sequence is employed where what may not be mastered in the previous unit will be practiced again when learning new material in subsequent units.

The authors attempted to eliminate dead-end chemistry topics which were not necessary to the learning of subsequent topics, and which did not allow for applications of the theoretical chemistry to everyday life. Practical chemistry and rigorous, theoretical chemistry can be made very compatible with one another and need not be mutually exclusive. The authors feel that they have only made a small, first attempt at integrating practical (everyday) and rigorous (theoretical) chemistry and that yearly revisions will improve the materials in this regard. Any suggestions from students and teachers as to how more practical, everyday chemistry could be integrated into the materials would be appreciated.

ACKNOWLEDGEMENTS

The materials contained in this course have evolved as a result of the initial work by members of the Edmonton Regional Chemistry Council. The Council members prepared the objectives for which the materials were written. The writing of the materials was made possible through the financial support of the Edmonton Public School Board and to a lesser extent the Edmonton Separate School Board.

The authors are indebted for the assistance and encouragement provided by the University of Alberta Departments of Chemistry and Secondary Education. Since the authors wanted to write materials which met the needs of Alberta students and classroom teachers, the feedback from the students and teachers has led to, and will continue to lead to, considerable revision of the materials. One of the fundamental precepts established for this local curriculum materials project was that classroom teachers are the experts in terms of what materials are needed in classroom instruction. Fortunately, the authors have been supported by the University and the School Boards in regard to the writing of materials by classroom teachers, and in regard to integrating everyday and theoretical chemistry.

The project is also indebted to the secretarial assistance of Dorothy Bell, Doris Cross, Marylin Kuzub and Anne Marie Sieber, and to the printing assistance of Gerry Mikytyshyn and his Industrial Arts students at Queen Elizabeth Composite High School.

Frank Jenkins - Queen Elizabeth Composite High School, Edmonton
George Klimiuk - Harry Ainlay Composite High School, Edmonton
Dean Hunt - Ross Sheppard Composite High School, Edmonton
Dick Tompkins - Queen Elizabeth Composite High School, Edmonton

PERIODIC TABLE OF THE ELEMENTS

KEY

Atomic Number	1
Melting point(°C)	-259
Boiling point(°C)	-253
Density(g/cm³)₃	0.071
Molar mass(g/mol)₂	1.01
Electronegativity	2.1
Atomic radii(nm)*	2.5
Symbol₁	H
Name	hydrogen

NOTES:
1. Black—solid.
   Red—gas.
   Slant—liquid.
   Outline—synthetically prepared.
2. Based upon carbon-12. ( ) indicates most stable or best known isotope.
3. Values for gaseous elements are for liquids at the boiling point.
4. Boiling point at 28 atmospheres.

*Bragg-Slater atomic radii in nanometers.
g-graphite.
w-white.

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 **H** 1.01 -259 -253 0.071 2.1 2.5 hydrogen																1 **H** 1.01 259 253 0.071 2.1 2.5 hydrogen	2 **He** 4.00 272 269 0.126 5.0 helium
3 **Li** 6.94 180 1347 0.53 1.0 14.5 lithium	4 **Be** 9.01 1278 2970 1.85 1.5 10.5 beryllium											5 **B** 10.8 2300 2550 2.34 2.0 8.5 boron	6 **C** 12.0 3550g 4827 2.26 2.5 7.0 carbon	7 **N** 14.0 210 196 0.81 3.0 6.5 nitrogen	8 **O** 16.0 -219 183 1.14 3.5 6.0 oxygen	9 **F** 19.0 220 188 1.505 5.0 fluorine	10 **Ne** 20.2 249 246 1.20 6.5 neon
11 **Na** 23.0 97.8 882 0.97 18.0 sodium	12 **Mg** 24.3 649 1090 1.74 1.2 15.0 magnesium											13 **Al** 27.0 660 2467 2.70 1.5 12.5 aluminum	14 **Si** 28.1 1410 2355 2.33 1.8 11.0 silicon	15 **P** 31.0 44.2w 280 1.82w 2.1 10.0 phosphorus	16 **S** 32.1 113 445 2.07 2.5 10.0 sulfur	17 **Cl** 35.5 101 35 1.56 [illegible] chlorine	18 **Ar** 39.9 189 186 1.40 9.5 argon
19 **K** 39.1 63.7 774 0.86 22.0 potassium	20 **Ca** 40.1 839 1484 1.55 1.0 18.0 calcium	21 **Sc** 45.0 1541 2831 3.0 1.3 16.0 scandium	22 **Ti** 47.9 1660 3287 4.51 1.5 14.0 titanium	23 **V** 50.9 1890 3380 6.1 1.6 13.5 vanadium	24 **Cr** 52.0 1857 2672 7.19 14.0 chromium	25 **Mn** 54.9 1245 1962 7.43 14.0 manganese	26 **Fe** 55.8 1535 2750 7.86 14.0 iron	27 **Co** 58.9 1495 2870 8.9 1.8 13.5 cobalt	28 **Ni** 58.7 1453 2732 8.9 13.5 nickel	29 **Cu** 63.5 1083 2567 8.96 13.5 copper	30 **Zn** 65.4 420 907 7.14 13 zinc	31 **Ga** 69.7 29.8 2403 5.91 13.0 gallium	32 **Ge** 72.6 937 2830 5.32 [illegible] germanium	33 **As** 74.9 817 613 5.72 11.5 arsenic	34 **Se** 79.0 217 685 4.79 11.5 selenium	35 **Br** 79.9 7.2 58 3.12 [illegible] bromine	36 **Kr** 83.8 [illegible] [illegible] [illegible] krypton
37 **Rb** 85.5 38.9 688 1.53 23.5 rubidium	38 **Sr** 87.6 768 1384 2.6 20.0 strontium	39 **Y** 88.9 1522 3338 4.47 1.3 18.0 yttrium	40 **Zr** 91.2 1852 4377 6.49 1.4 15.5 zirconium	41 **Nb** 92.9 2468 4742 8.4 14.5 niobium	42 **Mo** 95.9 2617 4612 10.2 1.8 14.5 molybdenum	43 **Tc** 98.9 2172 4877 11.5 1.9 13.5 technetium	44 **Ru** 101 2310 3900 12.2 2.2 13.0 ruthenium	45 **Rh** 103 1966 3727 12.4 2.2 13.5 rhodium	46 **Pd** 106 1552 3140 12.0 2.2 14.0 palladium	47 **Ag** 108 962 2212 10.5 1.9 16.0 silver	48 **Cd** 112 321 765 8.65 1.7 15.5 cadmium	49 **In** 115 156 2080 7.31 1.7 15.5 indium	50 **Sn** 119 232 2270 7.30 14.5 tin	51 **Sb** 122 630 1750 6.62 14.5 antimony	52 **Te** 127 449 990 6.24 14.0 tellurium	53 **I** 127 114 183 4.94 14.0 iodine	54 **Xe** 131 112 108 3.06 [illegible] xenon
55 **Cs** 133 28.4 678 1.90 26.0 cesium	56 **Ba** 137 725 1640 3.5 0.9 21.5 barium	57 **La** 139 920 3457 6.17 1.1 19.5 lanthanum	72 **Hf** 178 2227 4602 13.1 1.3 15.5 hafnium	73 **Ta** 181 2996 5425 16.6 1.5 14.5 tantalum	74 **W** 184 3410 5660 19.3 1.7 14.1 wolfram	75 **Re** 186 3180 5627 21.0 1.9 13.5 rhenium	76 **Os** 190 3045 5027 22.6 2.2 13.0 osmium	77 **Ir** 192 2410 4130 22.5 2.2 13.5 iridium	78 **Pt** 195 1772 3827 21.4 2.2 13.5 platinum	79 **Au** 197 1063 2807 19.3 2.4 13.5 gold	80 **Hg** 201 -38.4 357 13.6 1.9 15.0 mercury	81 **Tl** 204 303 1457 11.85 1.8 19.0 thallium	82 **Pb** 207 327 1740 11.4 1.8 — lead	83 **Bi** 209 271 1560 9.8 1.9 16.0 bismuth	84 **Po** (210) 254 962 (9.2) 2.0 19.0 polonium	85 **At** (210) 302 337 - astatine	86 **Rn** (222) 71 62 14.5 radon
87 **Fr** (223) (27) (677) — 0.7 francium	88 **Ra** (226) 700 1140 5.0 0.9 radium	89 **Ac** (227) 1050 3200 — 1.1 actinium	104														

58 **Ce** 140 799 3426 6.67 1.1 18.1 cerium	59 **Pr** 141 931 3512 6.77 1.1 18.2 praseodymium	60 **Nd** 144 1021 3068 7.00 1.2 18.2 neodymium	61 **Pm** (145) 1080 2460 — — promethium	62 **Sm** 150 1077 1791 7.54 1.2 18.1 samarium	63 **Eu** 152 822 1597 5.26 19.9 europium	64 **Gd** 157 1312 3266 7.89 1.1 17.9 gadolinium	65 **Tb** 159 1356 3123 8.27 1.2 18.0 terbium	66 **Dy** 163 1412 2562 8.54 18.0 dysprosium	67 **Ho** 165 1474 2695 8.80 1.2 17.9 holmium	68 **Er** 167 1529 2863 9.05 1.2 17.8 erbium	69 **Tm** 169 1545 1947 9.33 1.2 17.7 thulium	70 **Yb** 173 819 1194 6.98 1.1 19.4 ytterbium	71 **Lu** 175 1663 3395 9.84 1.2 17.5 lutetium
90 **Th** (232) 1750 4790 11.7 1.3 thorium	91 **Pa** (231) <1600 — 15.4 1.5 protactinium	92 **U** 238 1132 3818 19.1 1.7 uranium	93 **Np** (237) 640 3902 19.5 1.3 neptunium	94 **Pu** (244) 641 3232 — 1.3 plutonium	95 **Am** (243) 994 2607 11.7 1.3 americium	96 **Cm** (247) 1340 — — curium	97 **Bk** (247) — — — berkelium	98 **Cf** (247) — — — californium	99 **Es** (254) — — — einsteinium	100 **Fm** (257) — — — fermium	101 **Md** (256) — — — mendelevium	102 **No** (254) — — — nobelium	103 **Lr** (257) — — — lawrencium

ALCHEM

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ALCHEM PERIODIC TABLE OF IONS

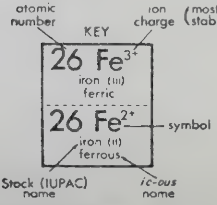
TABLE OF COMPLEX IONS

acetate	CH_3COO^-	chlorate	ClO_3^-	nitrate	NO_3^-	sulfite	SO_3^{2-}
ammonium	NH_4^+	perchlorate	ClO_4^-	nitrite	NO_2^-	hydrogensulfite bisulfite	HSO_3^-
benzoate	$C_6H_5COO^-$	chlorite	ClO_2^-	permanganate	MnO_4^-		
borate	BO_3^{3-}	hypochlorite	ClO^- or OCl^-	phosphate	PO_4^{3-}	thiosulfate	$S_2O_3^{2-}$
tetraborate	$B_4O_7^{2-}$	chromate	CrO_4^{2-}	hydrogenphosphate	HPO_4^{2-}	hydrogensulfide bisulfide	HS^-
bromate	BrO_3^-	dichromate	$Cr_2O_7^{2-}$	dihydrogenphosphate	$H_2PO_4^-$		
carbonate	CO_3^{2-}	cyanide	CN^-	silicate	SiO_3^{2-}		
hydrogencarbonate bicarbonate	HCO_3^-	glutamate	$C_5H_8NO_4^-$	sulfate	SO_4^{2-}		
		hydroxide	OH^-	hydrogensulfate bisulfate	HSO_4^-		
		iodate	IO_3^-				

GROUP IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H^+ hydrogen																1 H^- hydride	2 He helium
3 Li^+ lithium	4 Be^{2+} beryllium											5 B boron	6 C carbon 6 C^{4-} carbide	7 N^{3-} nitride	8 O^{2-} oxide	9 F^- fluoride	10 Ne neon
11 Na^+ sodium	12 Mg^{2+} magnesium											13 Al^{3+} aluminum	14 Si silicon	15 P^{3-} phosphide	16 S^{2-} sulfide	17 Cl^- chloride	18 Ar argon
19 K^+ potassium	20 Ca^{2+} calcium	21 Sc^{3+} scandium	22 Ti^{4+} titanium (IV) 22 Ti^{3+} titanium (III)	23 V^{5+} vanadium (V) 23 V^{4+} vanadium (IV)	24 Cr^{3+} chromium (III) 24 Cr^{2+} chromium (II)	25 Mn^{2+} manganese (II) 25 Mn^{4+} manganese (IV)	26 Fe^{3+} iron (III) ferric 26 Fe^{2+} iron (II) ferrous	27 Co^{2+} cobalt (II) 27 Co^{3+} cobalt (III)	28 Ni^{2+} nickel (II) nickelous 28 Ni^{3+} nickel (III) nickelic	29 Cu^{2+} copper (II) cupric 29 Cu^+ copper (I) cuprous	30 Zn^{2+} zinc	31 Ga^{3+} gallium	32 Ge^{4+} germanium	33 As^{3+} arsenic (III) arsenous 33 As^{5+} arsenic (V) arsenic	34 Se^{2-} selenide	35 Br^- bromide	36 Kr krypton
37 Rb^+ rubidium	38 Sr^{2+} strontium	39 Y^{3+} yttrium	40 Zr^{4+} zirconium	41 Nb^{5+} niobium (V) 41 Nb^{3+} niobium (III)	42 Mo^{6+} molybdenum	43 Tc^{7+} technetium	44 Ru^{3+} ruthenium (III) 44 Ru^{4+} ruthenium (IV)	45 Rh^{3+} rhodium	46 Pd^{2+} palladium (II) 46 Pd^{4+} palladium (IV)	47 Ag^+ silver	48 Cd^{2+} cadmium	49 In^{3+} indium	50 Sn^{4+} tin (IV) stannic 50 Sn^{2+} tin (II) stannous	51 Sb^{3+} antimony (III) stibnous 51 Sb^{5+} antimony (V) stibnic	52 Te^{2-} telluride	53 I^- iodide	54 Xe xenon
55 Cs^+ cesium	56 Ba^{2+} barium	57 La^{3+} lanthanum	72 Hf^{4+} hafnium	73 Ta^{5+} tantalum	74 W^{6+} wolfram	75 Re^{7+} rhenium	76 Os^{4+} osmium	77 Ir^{3+} iridium (III) 77 Ir^{4+} iridium (IV)	78 Pt^{4+} platinum (IV) 78 Pt^{2+} platinum (II)	79 Au^{3+} gold (III) 79 Au^+ gold (I)	80 Hg^{2+} mercury (II) mercuric 80 Hg^+ mercury (I) mercurous	81 Tl^+ thallium (I) 81 Tl^{3+} thallium (III)	82 Pb^{2+} lead (II) plumbous 82 Pb^{4+} lead (IV) plumbic	83 Bi^{3+} bismuth (III) 83 Bi^{5+} bismuth (V)	84 Po^{2+} polonium (II) 84 Po^{4+} polonium (IV)	85 At^- astatide	86 Rn radon
87 Fr^+ francium	88 Ra^{2+} radium	89 Ac^{3+} actinium	104														

58 Ce^{3+} cerium	59 Pr^{3+} praseodymium (III) 59 Pr^{4+} praseodymium (IV)	60 Nd^{3+} neodymium	61 Pm^{3+} promethium	62 Sm^{3+} samarium	63 Eu^{3+} europium (III) 63 Eu^{2+} europium (II)	64 Gd^{3+} gadolinium	65 Tb^{3+} terbium	66 Dy^{3+} dysprosium	67 Ho^{3+} holmium	68 Er^{3+} erbium	69 Tm^{3+} thulium	70 Yb^{3+} ytterbium	71 Lu^{3+} lutetium
90 Th^{4+} thorium	91 Pa^{5+} protactinium	92 U^{6+} uranium (VI) 92 U^{4+} uranium (IV)	93 Np^{5+} neptunium	94 Pu^{4+} plutonium (IV) 94 Pu^{6+} plutonium (VI)	95 Am^{3+} americium	96 Cm^{3+} curium	97 Bk^{3+} berkelium	98 Cf^{3+} californium	99 Es einsteinium	100 Fm fermium	101 Md mendelevium	102 No nobelium	103 Lr lawrencium

(most common or most stable ion listed on top)



5 B
boron

Shaded area indicates this element does not form ionic compounds.

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CHEMISTRY 10

THE MOLE CONCEPT

Name: ______________________________

A. THE MOLE AND ATOMIC WEIGHT

Atoms or molecules are extremely small particles and any workable sample of a substance involves many millions of these particles. The extreme smallness of atoms and molecules will appear evident from the following analog. Suppose that all the people on the earth were assigned the task of counting the molecules in a tablespoon of water at the rate of one molecule per second. Under these conditions approximately 8 million years would be required to complete the job. As impractical as this may seem, it does convey the idea that the number of atoms or molecules involved in any workable sample of a substance is so large that it staggers the imagination.

Fortunately, you will not be faced with the problem of weighing out individual atoms of an element or individual molecules of a compound. However, you will need to weigh out large numbers of atoms or molecules of different substances. Familiarity with the definitions relating to atomic weight permits this to be done quite simply. The following quantitative definitions will help your understanding of atomic weights.

1. The atomic weight (atomic mass) of an atom is the weight (mass) of an atom expressed relative to the carbon-12 isotope which is assigned a weight (mass) exactly equal to 12.

2. The Avogadro number, approximately 6.02×10^{23} is the number of carbon-12 atoms in the defined quantity of exactly 12 grams of carbon-12.

3. A mole of a substance is the amount of substance containing the Avogadro number of any kind of chemical unit (atom, molecule, formula unit).

4. The MOLAR MASS (gram-atomic weight) of the element is the mass in grams of one mole of naturally occurring atoms of an element.

NOTE: For purposes of this course the word "molar mass" can be used to mean gram-atomic weight or atomic weight expressed in the units grams per mole.

From the preceding definitions, it is evident that to weigh out one mole of carbon atoms, you must take one molar mass of carbon, 12.0 g. For weighing out one mole of hydrogen atoms, you must take one molar mass of hydrogen 1.01 g of hydrogen contains an equal number of atoms. Thus any given weights of carbon and hydrogen which are in the ratio of 12:1 (the ratio of their atomic weights) must have the same number of atoms. By similar reasoning, 6.00 g of carbon contains one-half as many atoms as 1.01 g of hydrogen and 24.0 g of carbon contains twice as many atoms as 1.01 of hydrogen.

It should be recognized that not only does the symbol for the element stand for one atom of that element, but in quantitative relationships, it stands for one mole of atoms of that element.

B. THE MOLE AND MOLECULAR WEIGHT AND/OR FORMULA WEIGHT

The concept of a mole of atoms of an element can be extended to a mole of molecules or formula units. One mole of O_2 molecules will contain two moles of O atoms. Since two moles of O atoms has a mass of 2 mol x 16.0 g/mol or 32.0 g, a mole of O_2 molecules must have the same mass, 32.0 g, which is the molar mass (gram-molecular weight) of O_2. One mole of H_2O molecules contains two moles of H atoms and one mole of O atoms. Two moles of H atoms has a mass of 2.02 g; one mole of O atoms has a mass of 16.0 g. Thus, by addition, one mole of H_2O molecules (molar mass of H_2O) must have a mass of 18.0 g. In the same way, it can be shown that the molar mass of methane, CH_4, is 16.0 g. The concept of the mole may also be extended to include those substances which do not exist as molecules, i.e., ionic compounds. Thus the molar mass (gram-formula weight) of sodium chloride, 58.5 g of NaCl, is one mole of this compound.

It should be apparent to you that a formula may represent one mole of molecules or one mole of formula units as well as one molecule or formula unit.

Note: It was indicated earlier that for purposes of this course, molar mass can be used to mean gram-atomic weight or atomic weight in grams per mole. Similarily, molar mass, in grams per mole, may be used to represent molecular weight and gram-molecular weight or formula weight and gram-formula weight.

C. AN OVERVIEW

There are several points regarding the mole concept that should be recognized and well remembered.

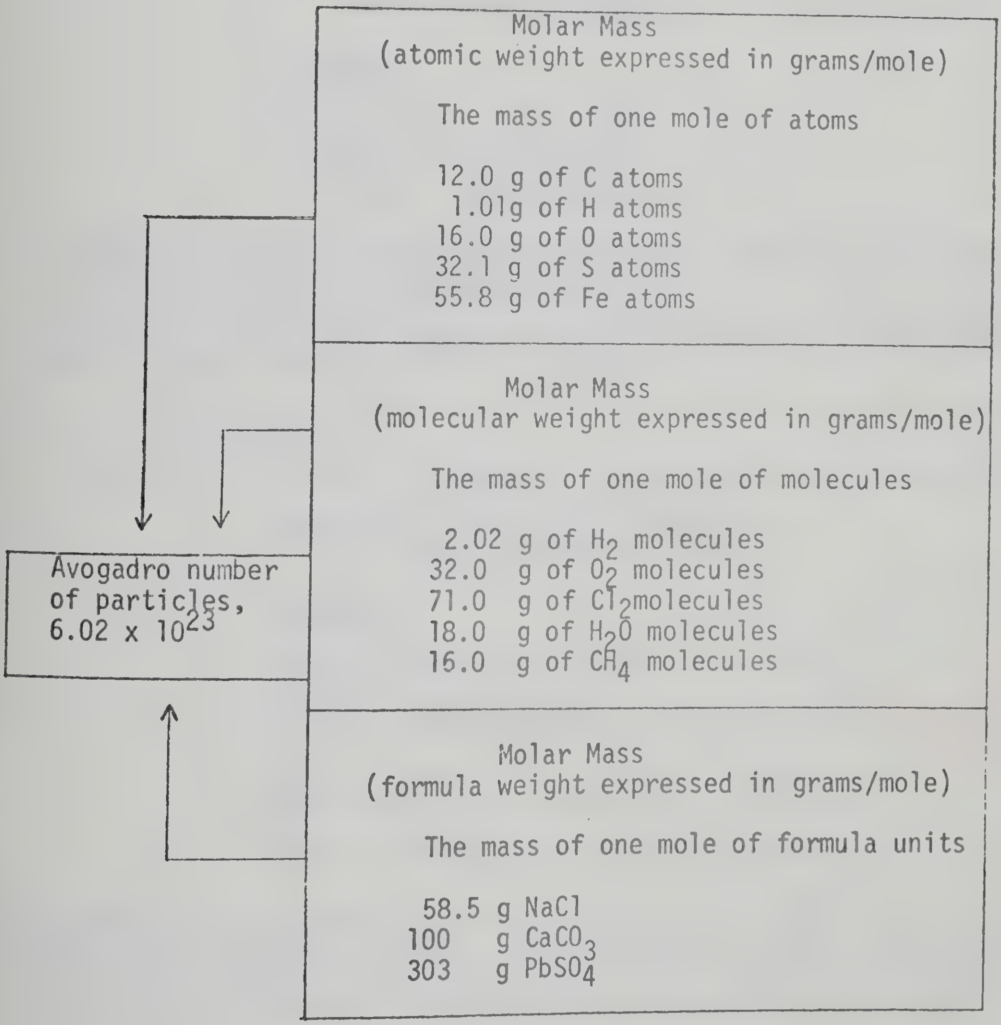
1. The quantity of substance containing the Avogadro number, approximately $6.02 \cdot x\ 10^{23}$, of any kind of chemical unit (atom, molecule, formula unit) is called a mole of that substance. This quantity of substance has a definite weight, which will be called the molar mass of this substance.

2. The mole is a defined quantity.

CHEMISTRY 10

Name: ____________________

THE MOLE CONCEPT



Molar Mass
(atomic weight expressed in grams/mole)

The mass of one mole of atoms

12.0 g of C atoms
1.01g of H atoms
16.0 g of O atoms
32.1 g of S atoms
55.8 g of Fe atoms

Molar Mass
(molecular weight expressed in grams/mole)

The mass of one mole of molecules

2.02 g of H_2 molecules
32.0 g of O_2 molecules
71.0 g of Cl_2molecules
18.0 g of H_2O molecules
16.0 g of CH_4 molecules

Molar Mass
(formula weight expressed in grams/mole)

The mass of one mole of formula units

58.5 g NaCl
100 g $CaCO_3$
303 g $PbSO_4$

Avogadro number of particles, 6.02×10^{23}

D. MASS-MOLE RELATIONSHIP

1. Mass-Mole Relationship

one dozen = 12 objects

Compare

12 erasers at 10.0 g each = 120 g
12 pencils at 5.00 g each = 60.0 g
12 dimes at 2.50 g each = 30.0 g

The mass of the packages are different because the mass of each kind of object is different. However, the ratios between the masses of the packages, 120 g; 60.0 g; 30.0 g, are the same as the ratios between the masses of the individual objects, 10.0 g; 5.00 g; 2.50 g since each package contains the same number of objects.

2. one mole = 6.02×10^{23} particles
(to three significant digits)

Compare

6.02×10^{23} helium atoms = 4.00 g

6.02×10^{23} hydrogen molecules = 2.02 g

6.02×10^{23} water molecules = 18.0 g

6.02×10^{23} NaCl formula units = 58.5 g

The mass of the mole varies just as the mass of the dozen varies. It depends upon what the particles are. However, the ratios between the masses of the moles are the same as the ratios between the masses of the individual particles since each mole contains the same number of particles.

3. The number of moles of a substance can be readily converted to mass in grams and mass in grams may be readily converted to moles. In either case, the molar mass in grams per mole must be used.

CHEMISTRY 10

CALCULATIONS INVOLVING MEASURED VALUES

Name: ______________________________

Since all measurements involve some uncertainty, the answers which are calculated using measured values must show the uncertainty. This uncertainty can be shown by writing the calculated answer to the correct number of significant digits. Two general rules that, in all instances, apply to calculations involving measured values are:

1. a "known" digit combined with an uncertain digit (by addition, subtraction, multiplication or division) ⟶ an uncertain digit.

2. any measured value or any calculation using measured values when expressed to the correct number of significant digits includes only one uncertain digit.

The above general rules as applied to some specific mathematical operations follow.

ADDITION AND SUBTRACTION

Rule: Round-off to the least number of decimal places, then add or subtract.

Example:

To add: 12.26② kg (the circled digits are uncertain)
+ 744.④ kg

Remember: first round-off then calculate

12.3 kg
+744.④ kg
756.⑦ kg (expressed to the correct number of significant digits)

CHEMISTRY 10

CALCULATIONS WITH MEASUREMENTS

Name: ______________________________

Add the following measurements. Express your answer to the correct number of significant digits.

1. 9.75 g + 3.439 g + 3.275 g = __________
2. 14.67 m + 3.928 m + 1.0042 m = __________
3. 900.0 cm + 14.26 cm + 3.0004 cm = __________
4. 600.379 g + 7.4268 g + 3.3 g = __________
5. 760 km + 42.9 km + 3.79 km = __________
6. 24 g + 36.9 g + 298.3 g = __________

Subtract the following measurements. Express your answer to the correct number of significant digits.

1. 47.639 g - 13.627 g = __________
2. 39 m - 14.880 m = __________
3. 19.349 ml - 19.33 ml = __________
4. 0.149 cm - 0.039 cm = __________
5. 37.92 g - 33.2 g = __________
6. 149.39 m - 14.2 m = __________

CHEMISTRY 10

MOLES OF ATOMS

Name: ______________________________

How many moles of each kind of atom are there in each of the following samples?

1. 1.0 mole of O_2 gas
2. 1.0 mole of water, HOH
3. 1.0 mole of sulfur trioxide
4. 3.0 moles of Na_2O
5. 7.5 moles of $Ca(OH)_2$
6. 4.0 moles of $K_2Cr_2O_7$
7. 2.3 moles of H_2SO_4
8. 9.26 moles of $Pb(NO_3)_2$
9. 0.512 moles of acetic acid
10. 0.0384 moles of magnesium bromate

CHEMISTRY 10

MOLAR MASS

Name: ______________________________

Calculate the molar mass of each of the following substances found in the Chemical Reactions Lab in the last unit. The molar mass should be expressed to three significant digits with the proper units.

1. magnesium
2. oxygen
3. $C_{25}H_{52}$
4. CH_4
5. HOH
6. calcium
7. $CuSO_4$
8. HCl
9. chlorine
10. sodium iodide
11. cobalt(II) chloride
12. H_2SO_4
13. sodium hydroxide
14. iron (III) chloride
15. Na_2CrO_4
16. potassium chloride
17. $NaNO_3$
18. potassium hydroxide
19. $BaCl_2$
20. $Co(NO_3)_2$

CHEMISTRY 10

MOLAR MASS

Name: ____

Calculate the molar mass of each of the following substances to three significant digits. Include the correct unit for each.

1. Ag

2. CO_2

3. SO_2

4. H_2SO_4

5. chlorine gas

6. sodium bicarbonate

7. $CaCO_3$

8. silver nitrate

9. MgO

10. HgO

11. C_2H_2

12. C_8H_{18}

13. aluminum sulfate

14. $(NH_4)_2SO_3$

15. $Sr(NO_3)_2$

CHEMISTRY 10

CALCULATIONS INVOLVING MEASURED VALUES

MULTIPLICATION AND DIVISION

RULE: Round-off the answer to the same number of significant digits as the value with the least number of significant digits used in the calculation.

Example: (uncertain digits are circled)

$$\begin{array}{r} 13.5\textcircled{2}\ \text{m} \\ 2.\textcircled{1}\ \text{kg} \\ \hline \textcircled{1}\textcircled{3}\textcircled{5}\textcircled{2} \\ 270\textcircled{4} \\ \hline 2\textcircled{8}\textcircled{3}\textcircled{9}\textcircled{2} \end{array}$$

Answer expressed to the correct number of significant digits is 28 kgm.

Additional examples:

a) $0.025 \text{ mole} \times 12.01 \frac{\text{g}}{\text{mole}} = 0.30 \text{ g}$ (expressed to the correct number of significant digits)

b) $7.56 \text{ m} \div 1000 \frac{\text{m}}{\text{km}} = 7.56 \times 10^{-3} \text{ km}$ (Note that 1000 m per km is a defined and exact quantity, i.e., it can be expressed to any number of significant digits)

CHEMISTRY 10

DIMENSIONAL (UNIT) ANALYSIS

(ALSO CALLED THE FACTOR-LABEL METHOD)

Name: ______________________________

The conversion of units is of great importance in chemistry problems. Dimensional analysis is a very useful method to follow for unit conversions. This method essentially involves two basis principles:

1. the existence of equivalence between various units, and
2. the equivalence between units can be used as a conversion factor to convert any number from one set of units to another by simple multiplication or division.

Examples:

1. One baseball has a mass of 140 g. Find the mass of 20 baseballs.

$$\text{mass of 20 baseballs} = 20 \text{ baseballs} \times \left(\frac{140 \text{ g}}{\text{baseball}}\right) = 2.80 \times 10^3 \text{g}$$

Note: The equivalence, 1 baseball = 140 g was used as the conversion factor $\frac{140 \text{ g}}{\text{baseball}}$ to convert baseballs to grams.

2. Find the number of kg in 243 g of a substance.

$$\text{mass} = \frac{243 \text{ g}}{\frac{1000 \text{ g}}{\text{kg}}} = 0.243 \text{ kg}$$

$$\text{or mass} = 243 \text{ g} \times \frac{1 \text{ kg}}{1000 \text{ g}} = 0.243 \text{ kg}$$

Note: the equivalence, 1 kg = 1000 g, was used as the conversion factor to convert g to kg.

CHEMISTRY 10

MASS - MOLE CONVERSIONS

Name: ______________________________

A. CONVERTING MASS TO MOLES

Converting mass to moles can be done by dividing the given mass in grams by the molar mass in grams/mole or multiplying the mass in grams by the reciprocal of molar mass, mole/gram. Note that the conversion is the equivalence between mass in grams and the mole.

Examples:

Determine the number of moles in:

a) 3.40 g of boron, B

$$\text{moles of B} = \frac{3.40\text{ g}}{10.8\text{ g/mol}} = 0.312\text{ mol}$$

or

$$\text{moles of B} = 3.40\text{ g} \times \frac{1\text{ mole}}{10.8\text{ g}} = 0.312\text{ mol}$$

Note: The conversion factor is the equivalence, 1 mole B = 10.8 g

b) 90.4 g of CH_4

$$\text{moles of } CH_4 = \frac{90.4\text{ g}}{16.0\text{ g/mol}} = 5.64\text{ mol}$$

or

$$\text{moles of } CH_4 = 90.4\text{ g} \times \frac{1\text{ mol}}{16.0\text{ g}} = 5.64\text{ mol}$$

Note: The conversion factor is the equivalence, 1 mole CH_4 = 16.0 g

c) 25.0 g of Na_2CO_3

$$\text{moles of } Na_2CO_3 = \frac{25.0\text{ g}}{106\text{ g/mol}} = 0.236\text{ mol}$$

or

$$\text{moles of } Na_2CO_3 = 25.0\text{ g} \times \frac{1\text{ mol}}{106\text{ g}} = 0.236\text{ mol}$$

Note: The conversion factor is the equivalence, 1 mole Na_2CO_3 = 106 g

B. CONVERTING MOLES TO MASS

Converting moles to mass can be done by multiplying the given number of moles by grams/mole. Note that the conversion factor is the equivalence between mass in grams and the mole.

Examples:

Determine the mass of

a) 1.25 moles of S_8

$$\text{mass of } S_8 = 1.25 \text{ mol} \times \frac{257 \text{ g}}{\text{mol}} = 321 \text{ g}$$

Note: The conversion factor is the equivalence, 1 mole S_8 = 257 g

b) 0.168 mole of H_2O

$$\text{mass of } H_2O = 0.168 \text{ mol} \times \frac{18.0 \text{ g}}{\text{mol}} = 3.02 \text{ g}$$

Note: The conversion factor is the equivalence, 1 mole of H_2O = 18.0 g

c) 9.24 moles of $Ca(OH)_2$

$$\text{mass of } Ca(OH)_2 = 9.24 \text{ mol} \times \frac{74.1 \text{ g}}{\text{mol}} = 685 \text{ g}$$

Note: The conversion factor is the equivalence, 1 mole of $Ca(OH)_2$ = 7

CHEMISTRY 10

MASS-TO - MOLES CALCULATIONS

Name: ______________________________

How many moles of each substance are there in each of the following samples? Include units and the correct number of significant digits in each case.

1. 142 g of Cl_2
2. 117 g of NaCl
3. 76.5 g of water, HOH
4. 8.8 g of CO_2
5. 150 g of Mg
6. 1.25 g of Cu
7. 9.81 g of H_2SO_4
8. 0.98 g of carbon monoxide
9. 68.8 g of lithium oxide
10. 1.36 kg of carbon tetrachloride

D9, D10

CHEMISTRY 10

MOLES-TO-MASS CALCULATIONS

Name: ________________________________

Find the mass in grams of each of the following samples of substances. Give the correct number of significant digits for each answer.

1. 0.036 moles of oxygen gas, O_2

2. 1.5 moles of silver nitrate, $AgNO_3$

3. 2.1 x 10^3 moles of Na_2O

4. 0.0792 moles of CO

5. 2.6 moles of Zn

6. 4.44 moles of HNO_3

7. 0.12 moles of sodium hydroxide

8. 1.20 moles of potassium dichromate

9. 4.05 moles of dinitrogen pentoxide

10. 0.0102 moles of magnesium nitrate

CHEMISTRY 10

MOLE CALCULATIONS - AN OVERVIEW

Name: ____________________

Solve the following. Where applicable, express your answer to the correct number of significant digits and in the correct units.

1. How many moles of O atoms are there in 3.75 moles of $(NH_4)_2SO_4$?

2. How many moles of H atoms are there in 19.6 grams of H_3PO_4?

3. What is the formula and molar mass of the compound sodium hypochlorite, an important component in bleach?

4. Find the molar mass of octane, C_8H_{18}, a component of gasoline.

5. Find the mass in grams of 0.0305 moles of zinc nitrate.

CHEMISTRY 10

6. Find the number of moles of sugar molecules in 454 g (about one pound) of sugar. (Sugar, or sucrose, is made up of $C_{12}H_{22}O_{11}$ molecules).

7. How many moles of formula units are there in 454 g (about one pound) of table salt, NaCl?

8. What is the mass of 0.0206 mole of baking soda (sodium bicarbonate)?

9. A student placed a strip of copper weighing 7.96 g in an acid. The copper was removed after three minutes and reweighed. It then weighed 4.29 g. How many moles of copper reacted with the acid?

10. The expression $7NH_4NO_3$ can be used to mean either 7 formula units or 7 moles of ammonium nitrate.

    (a) If the expression represents 7 formula units, what is the total number of atoms this would include?

    (b) If the expression represents 7 moles, what mass does it represent?

CHEMISTRY 10

Use the following data to answer the next five questions.

Suppose,

(a) atoms of element A have a molar mass of 15.0 g/mole;
(b) atoms of elements B have a molar mass of 41.5 g/mole;
(c) elements A and B combine to form a molecular compound; and
(d) two moles of A atoms combine with one mole of B atoms to form one mole of compound.

11. Give the formula for the compound.

12. What is the molar mass of the compound?

13. What is the mass of 0.630 mole of this compound?

14. 1.00 kg of this compound contains how many moles of molecules?

15. If B is more nonmetallic than A and A is named flangen and B is named drimfline, what is the name of the compound?

CHEMISTRY 10

LAB D4 MASS - MOLE RELATIONSHIPS

Name: ______________________________

Purpose

See mass-mole relationships Lab I

Procedure

1. In the data table provided record the names of samples and the moles of samples required as given by your teacher.
2. As a pre-lab exercise, write formulae for the sample and calculate the weight of the samples required.
3. Learn the correct technique for weighing a desired amount of substance. These are summarized below for your information
4. In the lab weigh the required amount of each sample by the method of weighing the container then weighing the container plus sample.
5. Record the weight of container and the weight of container plus sample in the data sheet.
6. Label the weighed samples and make them available for checking by your teacher.

Technique for Weighing Out a Desired Amount of Substance

A. Solids

1. Pour out the approximate amount needed on a clean piece of paper.
2. Weigh and record the weight of another clean piece of smooth paper.
3. Adjust the balance so you obtain the additional weight of the solid needed.
4. Tap the paper containing the approxinate amount gently to transfer the solid a little at a time onto the weighed paper on the balanced pan. If you should transfer too much, remove a few crystals with a spatula or a small piece of folded paper.

B. Liquids

1. Weigh the container.
2. Adjust the balance so that you obtain the additional weight of the liquid needed.
3. From a stock bottle pour out the approximate amount needed into the container.
4. Adjust to the correct weight by adding or removing liquid using a medicine dropper or pipette.

CHEMISTRY 10

	Name of Sample	Formula of Sample	Required Moles of Sample	Required Weight of Sample (Show Method of Calculation)	Weight of Container	Weight of Container plus Sample	Teacher Check
1.							
2.							
3.							
4.							
5.							

GRAVIMETRIC STOICHIOMETRY
INTRODUCTION

1 - 9
(under revision)

Stoichiometry

This unit is a first exposure to stoichiometry - the prediction of how much of one substance will react or be produced in a chemical reaction relative to the amount of another substance in the reaction. In this unit the amount of substances may be expressed as number of moles (in moles) or mass (in grams). *Gravimetric* stoichiometry refers to stoichiometry involving the measurement of *weight or mass* as opposed to measurement of solution volume or gas volume. *Solution* stoichiometry and *gas* stoichiometry will be studied in more advanced chemistry courses.

Stoichiometry is a Review

The study of gravimetric stoichiometry assumes a knowledge of Unit A (formulas of elements and ions), Unit B (nomenclature), Unit C (writing balanced chemical equations and predicting products for chemical reactions), and Unit D (converting mass to #moles and #moles to mass). In many ways gravimetric stoichiometry will serve as a review of the first four units of this course - refer back when necessary.

Practical Importance of Stoichiometry

Everyday applications of stoichiometry are numerous; some of these applications are listed below.

1. The gasoline to air mixture is regulated in a car or motorcycle by the carburetor. Proper proportions of gasoline and air are necessary for maximum power and gasoline mileage.
2. Since cooking food involves chemical reactions every recipe suggests the proper proportion of *chemicals* to produce a complete reaction. For example, if the proper proportions of baking soda and cream of tartar are not used, some of one or the other will be left over (in excess). An excess of one component may adversely affect the cooked *product.*
3. Antacid tablets may be harmful if taken in excess. Each antacid tablet contains a certain amount of chemical which neutralizes stomach acid. If too many tablets are taken, too much stomach acid is destroyed and proper digestion can not occur.

E1

CHEMISTRY 10

10.

MOLE-MOLE STOICHIOMETRY

NAME:______________________

Balance the following equations and use the ratio obtained to complete the table following each equation.

1. ______ H_2O → ______ H_2 + ______ O_2

H_2O	H_2	O_2
5.0 mol		
		0.600 mol
	3.00 mol	

2. ______ Na + ______ HOH → ______ H_2 + ______ NaOH

Na	HOH	H_2	NaOH
8.0 mol			
	0.20 mol		
		4.80 mol	
			16.0 mol

3. ____ $Al_2(SO_4)_3$ + ____ NH_4OH → ____ $Al(OH)_3$ + ____ $(NH_4)_2SO_4$

$Al_2(SO_4)_3$	NH_4OH	$Al(OH)_3$	$(NH_4)_2SO_4$
3.0 mol			
	2.0 mol		
		1.00 mol	
			1.00 mol

4. ____ C_4H_8 + ____ O_2 → ____ CO_2 + ____ H_2O

C_4H_8	O_2	CO_2	H_2O
			0.212 mol
		0.120 mol	
	18.0 mol		
0.32 mol			

5. ____ P_4 + ____ I_2 → ____ PI_3

P_4	I_2	PI_3
		2.82 mol
	0.396 mol	
2.5 mol		

CHEMISTRY 10

STOICHIOMETRIC CALCULATIONS

NAME: ______________________

Calculations based on quantities of substances involved in chemical reactions are known as stoichiometric calculations. Suppose two substances A and B combine to form a third substance C according to the reaction:

$$2A + B \rightarrow 2C$$

We wish to know the mass of B(desired substance) which will react with a measured quantity of A(starting substance). The solution to this type of problem consists of four steps.

STEP I: Write the balanced chemical equation.

$$2\,A + B \rightarrow 2C$$

STEP II: Convert mass of substance A(starting substance) to moles.

$$\text{moles of A} = \frac{\text{mass of A}}{\text{molar mass of A}} = \frac{\text{grams}}{\text{grams/mole}}$$

STEP III: Use the coefficients in the balanced equation to determine the number of moles of B(desired substance) needed to combine with the moles of A(starting substance) calculated in Step II.

$$\frac{\text{moles of B(desired substance)}}{\text{moles of A(starting substance)}} = \frac{1}{2}$$

or, in this case,

moles of B (desired substance) $= \frac{1}{2}$ x moles of A (starting substance)

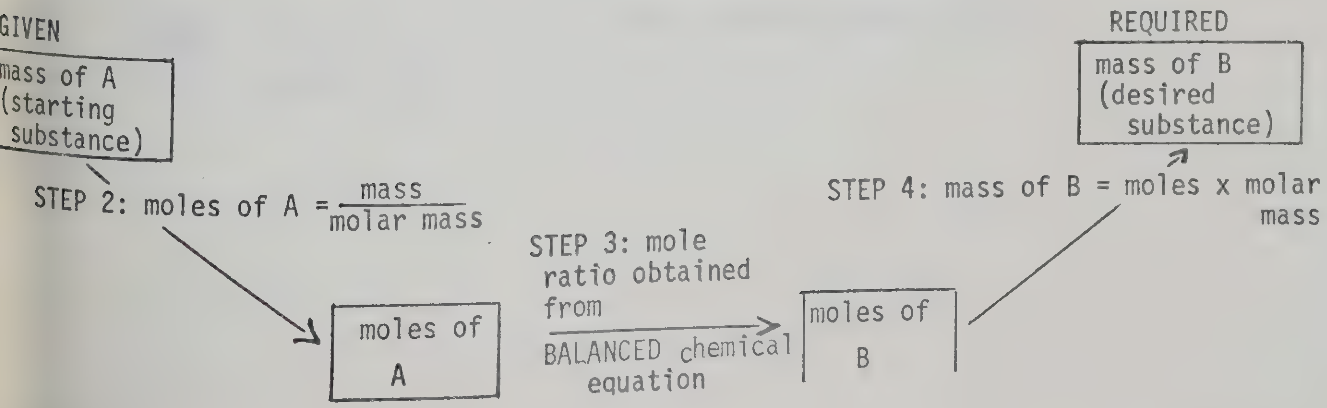
STEP IV: Convert moles of B to mass of B.

mass of B = moles of B x molar mass of B

= moles x grams/mole

The four general steps are summarized in the following STOICHIOMETRY FLOW CHART:

STEP 1: Write the balanced chemcial equation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mass of A (starting substance)
STEP 2: moles of A = mass / molar mass
moles of A
STEP 3: mole ratio obtained from BALANCED chemical equation
moles of B
STEP 4: mass of B = moles x molar mass
REQUIRED
mass of B (desired substance)

EXAMPLE #1 OF STOICHIOMETRIC CALCULATIONS

NAME:________________________

PROBLEM: Hydrogen gas, H_2, reacts with oxygen gas, O_2, to produce water vapour, H_2O. 8.08 grams of H_2 will react with what mass of O_2 to produce H_2O.

STEP I: Write the balanced chemcial equation.

$$2\ H_2 + O_2 \longrightarrow 2H_2O$$

STEP II: Convert mass of H_2 to moles of H_2.

$$\text{moles of } H_2 = \frac{\text{mass}}{\text{molar mass}} = \frac{8.08\ \text{g}}{2.02\ \text{g/mol}}$$

$$= 4.00\ \text{mol}$$

STEP III: Use the coefficients in the balanced equation to determine the number of moles of O_2 that will combine with 4.00 moles of H_2.

$$\frac{\text{moles of } O_2}{\text{moles of } H_2} = \frac{1}{2}$$

$$\text{moles of } O_2 = \frac{1}{2} \times 4.00\ \text{mol} = 2.00\ \text{mol}$$

STEP IV: Convert moles of O_2 to mass of O_2.

$$\begin{aligned}\text{mass of } O_2 &= \text{moles} \times \text{molar mass}\\ &= 2.00\ \text{mol} \times 32.0\ \text{g/mol}\\ &= 64.0\ \text{g}\end{aligned}$$

ANSWER: 8.08 grams of H_2 will react with 64.0 grams of O_2 to produce H_2O.

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CHEMISTRY 10

EXAMPLE #2 OF STOICHIOMETRIC CALCULATIONS

NAME :____________________

PROBLEM: Methane, CH_4, burns to produce water, H_2O, and carbon dioxide, CO_2. What mass of CH_4 is needed to produce 9.00 grams of H_2O?

STEP I: Write the balanced chemical equation.

$$CH_4 + O_2 \longrightarrow 2H_2O + CO_2$$

STEP II: Convert mass of H_2O to moles of H_2O.

$$\text{moles of } H_2O = \frac{\text{mass}}{\text{molar mass}} = \frac{9.00\ g}{18.0\ g/mol}$$

$$= 0.500\ mol$$

STEP III: Use the coefficients in the balanced equation to determine the number of moles of CH_4 needed to produce 0.500 mole of H_2O.

$$\frac{\text{moles of } CH_4}{\text{moles of } H_2O} = \frac{1}{2}$$

$$\text{moles of } CH_4 = \frac{1}{2} \times 0.500\ mol = 0.250\ mol$$

STEP IV: Convert moles of CH_4 to mass of CH_4.

$$\text{mass of } CH_4 = \text{moles} \times \text{molar mass}$$
$$= 0.250\ mol \times 16.0\ g/mol$$
$$= 4.00\ g$$

ANSWER: 9.00 grams of H_2O may be produced by the complete combustion of 4.00 grams of CH_4.

GRAVIMETRIC STOICHIOMETRY PROBLEMS

NAME: ____________________

Answer the following problems.

Refer to Chemical Reactions Lab III-Unit C for the equations for the following reactions.

Show all calculations in the space provided.

1. 48.6 grams of magnesium, Mg, will produce how many moles of magnesium oxide, MgO, when reacted with excess oxygen?

2. What mass of candle wax, assume $C_{25}H_{52}$, when burned in O_2 is needed to produce 12.5 moles of CO_2.

3. 4.00 grams of methane, CH_4, will require how many moles of oxygen, O_2, for complete combustion?

4. If 5.00 moles of water, H_2O, are decomposed, what mass of each product will be formed?

5. If 0.200 moles of calcium hydroxide, $Ca(OH)_2$, are produced, what mass of calcium, Ca, must have reacted with water?

6. What mass of chlorine, Cl_2, is needed to produce 63.5 grams of I_2, when chlorine reacts with NaI?

7. What mass of zinc is required to react with sufficient hydrochloric acid to produce 16 grams of hydrogen, H_2?

8. What mass of iron will combine with sufficient oxygen to yield 16.0 g of iron(III) oxide?

9. What mass of yellow PbI_2 precipitate will be produced when 6.62 g of $Pb(NO_3)_2$ reacts with excess NaI?

10. If 288 grams of cobalt(II) hydroxide are produced, what mass of sodium chloride must also have been produced when cobalt(II) chloride reacts with sodium hydroxide?

11. If 18.6 g of cobalt(II)nitrate, $Co(NO_3)_2$, are reacted with sufficient sodium hydroxide, NaOH, what mass of the precipitate, cobalt hydroxide, will form?

12. If 624 grams of barium chloride react with 486 grams of sodium chromate, what is the total mass of all products produced?

13. If 54.1 grams of iron(III) chloride combine with exactly 40.0 grams of sodium hydroxide, what is the mass of each product formed?

14. What mass of sodium nitrate will combine with 100 grams of potassium chloride?

15. What mass of each of $NaOH$ and H_2SO_4 are necessary to produce 23.8 grams of Na_2SO_4?

CHEMISTRY 10

GRAVIMETRIC STOICHIOMETRY

NAME: ______________________________

Solve the following problems. Show all calculations in the space provided.

1. A student wishes to prepare silver chloride according to the following balanced equation:

   $$BaCl_2 + 2AgNO_3 \rightarrow 2AgCl + Ba(NO_3)_2$$

   Predict the mass of $BaCl_2$ and the mass of $AgNO_3$ needed to produce 57.4 grams of AgCl.

2. A student places 19.09 grams of zinc metal in a copper sulfate solution to produce copper metal and zinc sulfate. After 24 hours the zinc strip is removed and its mass is recorded as 6.00 grams. Predict the mass of copper metal which should be produced by this reaction.

GRAVIMETRIC STOICHIOMETRY

NAME:______________________________

3. 4.80 grams of methane are burned in the lab. Predict the mass of carbon dioxide which this mass of methane should form.

4. 100 grams of ferric sulfate are mixed with what mass of calcium nitrate to give a double replacement reaction?

5. A manufacturer wishes to produce one ton (approx. 9.08×10^2kg) of ammonia by the Haber process.

$$N_2 + 3H_2 \rightarrow 2NH_3$$

Assuming that sufficient N_2 is available, what mass of H_2 is required to produce the required amount of ammonia?

CHEMISTRY 10

LAB III - UNIT E

THE REACTION OF SOLID COPPER WITH AQUEOUS SILVER NITRATE - A SINGLE REPLACEMENT REACTION.

NAME: ______________________

Materials

1 - vial containing silver nitrate
1 - length of heavy gauge copper wire
1 - centigram balance
1 - wash bottle containing distilled water
1 - large beaker (400 ml or larger)
1 - 250 ml beaker
1 - stirring rod
1 - watch glass
1 - ring stand
1 - funnel holder
1 - filter funnel
1 - piece of quantitative filter paper
1 - small quantity of steel wool

Procedure First day (30 minutes). Record all measurements.

1. Record the number of your centigram balance.
2. Weigh the vial containing silver nitrate (to 0.01 g).
3. Pour the silver nitrate crystals into the 250 ml beaker.
4. Weigh the empty vial (to 0.01 g).
5. Rub the copper wire with steel wool to clean its surface of oxides or lacquer.
6. Weigh the copper wire (to 0.01 g).
7. Form the copper wire into a coil about 10 cm long with a 20 cm handle. This can be done by wrapping it around a small test tube.

8. Add about 125 ml of distilled water to the silver nitrate in the beaker. (Beaker should be about 1/2 full).
9. Stir the mixture with a glass stirring rod until the silver nitrate crystals dissolve completely. Rinse off the stirring rod into the beaker as you remove it from the beaker.
10. Place the coil of copper into the silver nitrate solution and write visual observations for the first few minutes of the reaction.
11. Label the beaker with your initials, cover with a watch glass, and put the beaker away until next day.

CHEMISTRY 10

LAB III - UNIT E

NAME: ______________________

Procedure (Continued) Second Day (20 minutes)

12. The reaction has now stopped. Write your visual observations about the contents of the beaker.
13. Remove the copper coil from the solution, hold it over the beaker, and use your wash bottle to rinse any particles of silver (that may be sticking to the coil) into the beaker.
14. Allow the copper to dry on a paper towel. Weigh the copper (to 0.01 g), then discard it.
15. Weigh a clean piece of filter paper (to 0.01 g).
16. Set up a filtration system (as demonstrated) and filter out the silver crystals from the mixture in your beaker.Catch the filtrate in your large beaker. The filtrate is the clear solution that has gone through the filter paper.
17. Wash the silver with distilled water several (4-5) times, allowing complete draining after each wash.
18. Discard the filtrate.
19. Carefully remove the filter paper containing silver crystals from the funnel and place it in the 250 ml beaker again.
20. Make sure the beaker is labelled clearly and place it in a drying system until next day.

Procedure - Third day (10 minutes)

21. Remove the dry silver crystals together with the filter paper from the beaker and weigh (to 0.01 g) the filter paper plus crystals.
22. Place the silver into a designated beaker as instructed by your teacher.
23. Clean up your work area.

OBSERVATIONS

First day: balance number ______________________

mass of vial and $AgNO_3$ ______________________

mass of empty vial ______________________

mass of Cu wire before reaction ______________________

Visual Observations

CHEMISTRY 10

23.

LAB III - UNIT E

NAME: ____________________

Second day:

Visual Observations

mass of Cu wire after reaction ____________________

mass of filter paper ____________________

Third day:

mass of filter paper plus Ag ____________________

CALCULATIONS AND QUESTIONS. Show all work!

1. Find the mass of your $AgNO_3$ sample.

2. Find the mass of Cu that was used up in the reaction.

3. Find the mass of Ag produced.

4. The reaction proceeds slowly for a few hours and then stops. Explain why it stops in terms of the amount of reactants used.

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LAB III - UNIT E

NAME:____________________

5. Write a balanced chemical equation for the reaction that takes place.

NOTE: The mass of silver produced can be predicted by a stoichiometry calculation starting either from the amount of $AgNO_3$ that reacted or the amount of Cu that reacted.

6. Based on the amount of silver nitrate that reacted, predict the mass of silver that should form in your reaction.

Optional

7.(a) Based on the amount of copper that reacted, predict the mass of silver that should form in your reaction.

(b) Compare your answers from 6 and 7 (a)

8. How does the mass of silver actually produced in your reaction compare with the mass predicted in your calculation?

CHEMISTRY 10

LAB III - UNIT E

NAME:__________________________

9. (OPTIONAL) Calculate the per cent yield of silver for your reaction.

$$\% \text{ yield} = \frac{\text{actual mass Ag produced}}{\text{predicted mass of Ag}} \times 100$$

$$= \frac{\qquad}{\qquad} \times 100 = \underline{\qquad\qquad}$$

The copper nitrate formed in this reaction was dissolved in water and was discarded in the filtrate. It could have been collected and weighed by carefully boiling away all of the water, but this is a long process.

10. Based on the mass of Ag that you produced, calculate the mass of $Cu(NO_3)_2$ that you produced.

CHEMISTRY 10

LAB IV - UNIT E

NAME: ____________________

THE REACTION (IN WATER SOLUTION) OF LEAD (II) NITRATE WITH POTASSIUM IODIDE. DOUBLE REPLACEMENT.

Materials

1 - vial containing potassium iodide sample
1 - centigram balance
1 - piece quantitative filter paper
2 - 250 ml beaker
1 - 400 ml (or larger) beaker
2 - stirring rods
1 - wash bottle of distilled water
1 - watch glass
1 - spatula or scoopula
1 - ring stand
1 - filter funnel
1 - funnel holder

Procedure

DAY 1: (30 minutes)

1. Record your balance number.
2. Weigh the vial containing potassium iodide (to 0.01 g).
3. Pour the potassium iodide into a clean dry 250 ml beaker. Label this beaker #1.
4. Weigh the empty vial (to 0.01 g).
5. Weigh out exactly 3.00 grams of lead(II)nitrate. Refer to your Unit D guide sheet on weighing out a solid sample. Take a small amount of lead (II) nitrate (about 1 teaspoon) from the stock bottle on a clean piece of paper. Carry the lead (II) nitrate on the paper to the work area.
6. Weigh a clean, dry piece of paper on your balance, then advance the weights (or dial) by exactly 3.00 grams. Now add the solid chemical slowly with a scoopula until the balance reads level again. Discard any excess.
7. Pour the lead (II) nitrate into a clean 250 ml beaker. Label this beaker #2.
8. Add about 75-100 ml (no more) of distilled water to each beaker and stir each until the solids dissolve completely. Wash off the stirring rods into the respective beakers as you remove them.
9. Pour the contents of beaker #1 into beaker #2. Rinse beaker #1 into beaker #2 with your wash bottle.
10. Write your visual observations about this reaction. A solid that forms from a reaction between solutions like this is called a precipitate.
11. Cover the beaker. Label it with your initials and put it away until next day.

CHEMISTRY 10

LAB IV - UNIT E

NAME: ____________________

DAY 2: (20 minutes)

12. Weigh a clean piece of filter paper.
13. Set up a filtration system and filter out the yellow lead (II) iodide from the mixture in beaker #2. If the yellow solid sticks to the beaker, you can loosen it with a stirring rod or rubber policeman.
14. When you have all the PbI_2 transferred to the filter paper, wash it 4-5 times with distilled water.
15. Carefully remove the filter paper containing PbI_2 from the funnel, and place it back in beaker #2 to be dried.
16. Place the beaker containing the filter paper and PbI_2 into a drying apparatus. Make sure the beaker is clearly labelled.

DAY 3: (10 minutes)

17. Carefully remove the filter paper containing PbI_2 from the beaker and weigh the paper plus PbI_2 to 0.01 g).
18. Clean your work area.

OBSERVATIONS

Day 1: balance number ____________________

mass of sample vial plus KI ____________________

mass of empty sample vial ____________________

mass of paper plus $Pb(NO_3)_2$ ____________________

mass of paper ____________________

Day 2: mass of filter paper ____________________

Day 3: mass of filter paper plus PbI_2 ____________________

CALCULATIONS AND QUESTIONS (Show all work)

1. Find the mass of KI in your initial sample.

2. Find the mass of PbI_2 produced.

3. Find the number of moles of KI in your initial sample.

4. Find the number of moles of $Pb(NO_3)_2$ in your initial sample.

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LAB IV - UNIT F

NAME: ____________________

5. Write the balanced equation for this reaction

___ ________ + ___ ______ → ___ ________ + ____ __________
precipitate

6. (OPTIONAL) Which reactant is the "limited reactant"?

7. From the amount of KI in your sample predict the mass of PbI_2 that should form in this reaction.

8. (OPTIONAL) Can you use the amount of $Pb(NO_3)_2$ in your sample to predict the amount of PbI_2 that will form? If not, why not?

9. From the amount of KI in your initial sample, calculate the mass of $Pb(NO_3)_2$ needed to completely react with this much KI.

10. (OPTIONAL) Use % yield to compare your yield of PbI_2 (actual) with the amount predicted in calculation 7.

$$\% \text{ yield} = \frac{\text{actual yield } PbI_2}{\text{predicted yield } PbI_2} \times 100 = \_\_\_\_\_\_\_\_\_\_$$

$$= \frac{\_\_\_\_\_\_\_\_\_\_}{} \times 100 = \boxed{}$$

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